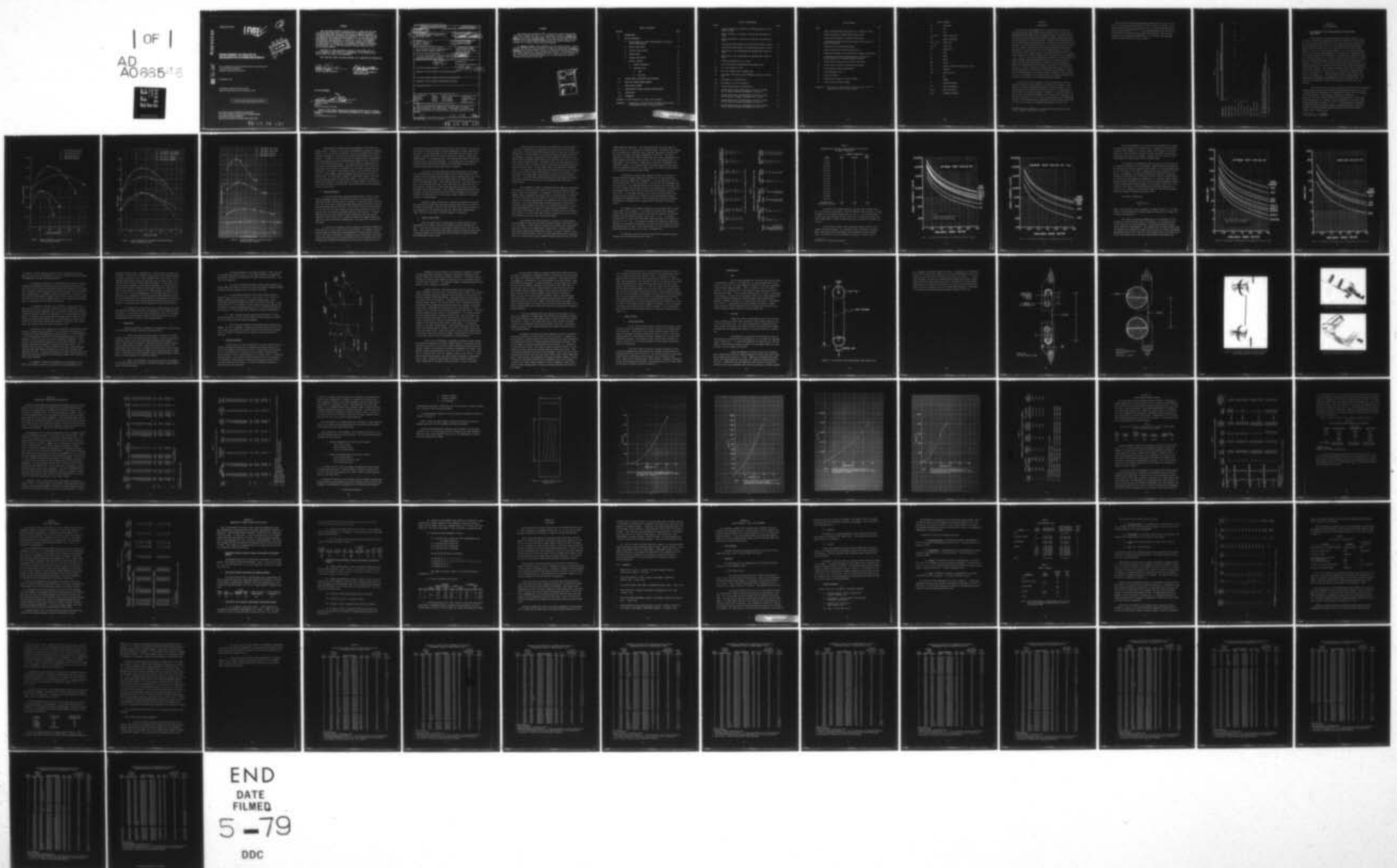
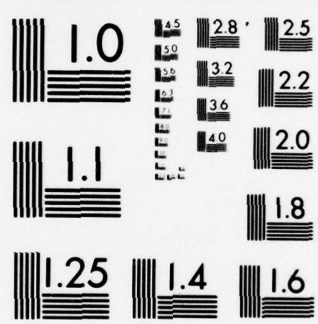
AD-A066 546   ALBANY INTERNATIONAL CORP DEDHAM MA FRL DIV   F/G 11/9
DEVELOPMENT OF KEVLAR 29 DECELERATOR SYSTEMS MATERIALS.(U)
NOV 78   N J ABBOTT, R J COSKREN   F33615-77-C-3007
UNCLASSIFIED   AFFDL-TR-78-201   NL

| OF |

AD
A066546



END
DATE
FILMED
5-79
DDC


1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

AFFDL-TR-78-201

LEVEL II

AD A0 66546

DDC FILE COPY

DEVELOPMENT OF KEVLAR 29 DECELERATOR SYSTEMS MATERIALS

FRL, A DIVISION OF ALBANY INTERNATIONAL CORPORATION
1000 PROVIDENCE HIGHWAY
DEDHAM, MASSACHUSETTS 02026

NOVEMBER 1978

TECHNICAL REPORT AFFDL-TR-78-201
Report for Period February 1977 to September 1978

Approved for public release; distribution unlimited.

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

References to named commercial products in this report are not to be considered in any sense as an endorsement of the product by the United States Air Force or the Government.

This technical report has been reviewed and is approved for publication.

William R. Pinnell
WILLIAM R. PINNELL
Project Engineer/Scientist

R. Harley Walker
R. HARLEY WALKER
Group Leader, Crew Escape & Subsystems Branch

FOR THE COMMANDER

Ambrose B. Nutt
AMBROSE B. NUTT
Director
Vehicle Equipment Division

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

19 REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. [redacted] — 18 AFFDL-TR-78-201	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) — 6 DEVELOPMENT OF KEVLAR 29 DECELERATOR SYSTEMS MATERIALS.		5. [redacted]OD COVERED — 9 Technical Report, Feb[redacted]77-Sep[redacted]78,
		6. [redacted]
7. AUTHOR(s) — 10 Norman J. Abbott, Robert J. Coskren		8. [redacted]NUMBER(s) — 15 F33615-77-C-3007
9. PERFORMING ORGANIZATION NAME AND ADDRESS — FRL, a Division of Albany International Corp, 1000 Providence Highway, Dedham, MA		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS — Program Element 62201F, Project 2402, Task 240203, Work Unit 24020311
11. CONTROLLING OFFICE NAME AND ADDRESS — Air Force Flight Dynamics Laboratory (FER), AF Wright Aeronautical Laboratories, AFSC, Wright-Patterson AFB, Ohio 45433		12. REPORT DATE — 11 Nov[redacted]78
		13. NUMBER OF PAGES — 77
14. MONITORING AGENCY NAME & ADDRESS (*if different from Controlling Office*) — 12 85p.		15. SECURITY CLASS. (*of this report*) — UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE — N/A

16 2402 17 03

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for Public Release: Distribution Unlimited

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

Approved for Public Release: Distribution Unlimited

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Kevlar Materials, parachutes, decelerators, ribbons, tapes, webbings, cords, threads, Military Specifications, fabric design, resin coating, joint strength, Strength translation efficiency, strength-to-weight ratio, tensile testing.

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Designs for decelerator systems materials made from Kevlar 29 have been developed consisting of 4 braided cords, 1 sewing thread, 12 ribbons, 10 tapes and webbings, and 2 canopy fabrics. Draft Military Specifications have been written for all of these materials, and sample quantities of each produced.

393 692 Gm

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

79 03 26 121

FOREWORD

This report was prepared by FRL, a Division of Albany International Corporation, Dedham, MA, under U. S. Government Contract No. F33615-77-C-3007. The work was initiated under Project 2402, and was conducted from February 1977 through September 1978. It was administered under the direction of the Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, with Mr. W. R. Pinnell acting as Project Engineer.

Mr. Norman J. Abbott was responsible for the overall program. Design, weaving and testing of the materials was under the supervision of Robert J. Coskren, with the assistance of Donat J. LaPointe who directed the weaving activities and Loren E. Atkins who carried out most of the laboratory tests. The authors express their appreciation to Dr. Milton M. Platt, Director of FRL, for handling contractual matters and for many helpful discussions throughout the course of the work.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF SYMBOLS

cm	centimeter
in, "	inch
ft	foot
yd, lin yd	yard, linear yard
cm^2	square centimeter
sq ft, ft^2	square foot
cf, ft^3	cubic foot
yd^2	square yard
g	gram
oz	ounce
lb	pound
min	minute
den	denier, grams per 9000 meters of yarn
dia	diameter
tpi	turns per inch
/	per
°	degree
°F	degree Fahrenheit
RH	relative humidity
W x F	warp and filling
S/W	strength-to-weight

SECTION I

INTRODUCTION

Interest in the use of Kevlar 29* as a replacement for nylon in decelerator materials results from its high tenacity, which in yarn form is approximately three times that of high tenacity nylon. This gives rise to the possibility of developing Kevlar materials weighing significantly less than nylon materials of the same strength. How much this weight difference will be depends upon how efficiently one can translate yarn strength into the strength of a woven or braided structure. In the case of nylon, and of other fibers of "normal" textile properties, strength translation efficiencies approach 100%. Kevlar, however, has other characteristics which make it unlike other textile fibers, namely a low rupture elongation (~4%), a high tensile modulus (~500 grams per denier) and a low yield strain in compression (~1%). Because of this unique combination of properties, we cannot expect to achieve optimum strength translation efficiency in Kevlar materials by weaving the same structural geometry as exists in the nylon structures. Rather, new geometries must be developed to suit Kevlar's characteristics, and there is no way of predicting in advance what these might be for best strength translation, nor how high the optimum efficiency may be. Development of optimum structures is initially largely a matter of trial and error, though it is reasonable to hope that experience will generate design principles which can be applied in developing additional materials.

To some extent this has happened, though in many ways the design of optimum structures of Kevlar remains a trial-and-error procedure. Unexpected, or at least inadequately understood, results are common, so that although apparently logical design changes are made, the consequences of these changes are seldom predictable. In general, it has been possible to achieve 70% to 80% strength translation efficiency in Kevlar materials, and their weight has been 1/2 to 1/3 that of a nylon material of corresponding strength. Using these materials, decelerator systems weighing no more than 1/2 that of nylon systems of comparable performance have been built.

*Du Pont registered trademark for its high strength high modulus aramid fiber, hereafter referred to as "Kevlar."

Many Kevlar decelerator materials were designed by FRL for the U.S. Air Force in a previous contract (F33615-73-C-5034). They are described in the final technical report for that work[1] as well as in several military specifications recently issued.[2,3,4,5,6] In the work described herein, some 29 additional Kevlar decelerator materials have been designed. These are also included in the referenced specifications. A list of the items developed under the current contract is given in Table 1.

TABLE 1

KEVLAR ITEMS DEVELOPED UNDER CONTRACT NO. F33615-77-C-3007

Description		Rated Strength (pounds)																					
		100	115	200	250	300	350	400	500	600	750	800	1000	1100	1500	2000	2500	2750	3000	4000	5000	6000	8000
Braided Cord[1]		III			*													*			XI		
Sewing Thread			*																				
Narrow Fabric[2]																							
2 inch wide	XI-							3		5		7	9		11	13	14		15	16	17	*	19
1-3/4 inch wide	X-												1						*				
1-1/2 inch wide	IX-								1					2					5				
1 inch wide	VI-						*				3				5				7				
1/2 inch wide	I-											3											
Broad Fabric																							
200 x 200 lb/inch[3]				*																			
300 x 300 lb/inch[3]						*																	

1. Type numbers from MIL-C-87129 given where applicable.
2. Type and class numbers from MIL-T-87130 given where applicable.
3. Air permeability 50-90 cf/sq ft-min; strength in warp and filling directions.

*Developed but not yet included in Military Specifications.

SECTION II

DESIGN PRINCIPLES

A. Yarn Strength vs. Twist Relationships for Various Kevlar Yarn Deniers

At the outset of the previous contract (F33615-73-C-5034), i.e., in June 1974, a study of the influence of twist on the strength of Rotoset Kevlar yarn of various deniers was made and it was from this work that optimum twist levels were established for each of the four commercially available deniers. Optimum values were found to be 4 to 6 turns per inch for the 200 and 400 deniers, 3 to 5 tpi for the 1000 denier and 2.5 to 3.5 tpi for the 1500 denier. These twist levels were used throughout the previous work in designing various Kevlar braids, narrow, and broad fabrics. All parent yarn originally furnished by Du Pont was "Rotoset," i.e. contained no twist but rather relied on a slight amount of filament entanglement to hold the fiber bundles together prior to twisting. In February 1977 the 400 denier Kevlar yarn delivered by the Du Pont Company was found to have essentially zero twist without Rotoset entanglement as previously supplied. (The so-called "producer's twist" may be slightly more than zero but less than 1 turn per inch. It is referred to throughout this report as "zero twist".) A similar change was noted in the 200 denier yarn received in November 1977. The major effect of these changes appears to be reproducing air permeability measurements made with the original yarn. (The 1000 and 1500 denier yarns continue to be supplied in Rotoset form by the producer.)

During the course of the present program it was found that the lightweight ribbons could be designed using less than the optimum warp yarn twist in order to produce lower air permeability at minimum weight and with little if any loss in tensile strength. It was decided, therefore, to restudy the effect of twist on the tensile strength of the various deniers so that a more up-to-date picture of its influence could be ascertained. This work is summarized graphically in Figures 1, 2, and 3. Tensile strength in grams/denier is shown as a function of twist (Figure 1) and Twist Multiplier* (Figure 2). Figure 3 is a plot of absolute breaking strength of yarns of each denier against twist in turns per inch.

---

*Twist Multiplier = $\frac{\text{tpi}\sqrt{\text{denier}}}{73}$.

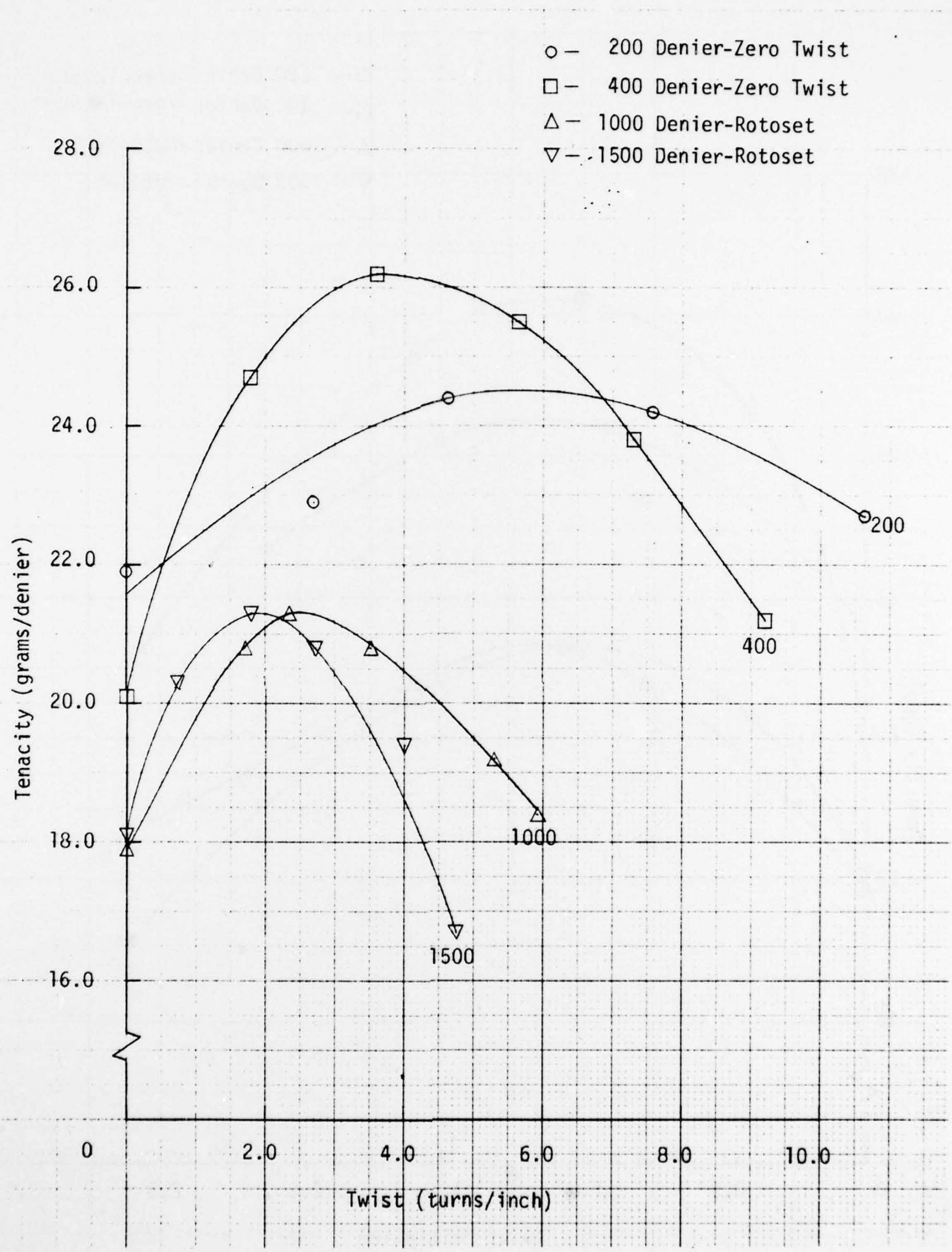


Figure 1. Rupture Tenacity as a Function of Twist for Four Kevlar 29 Yarns

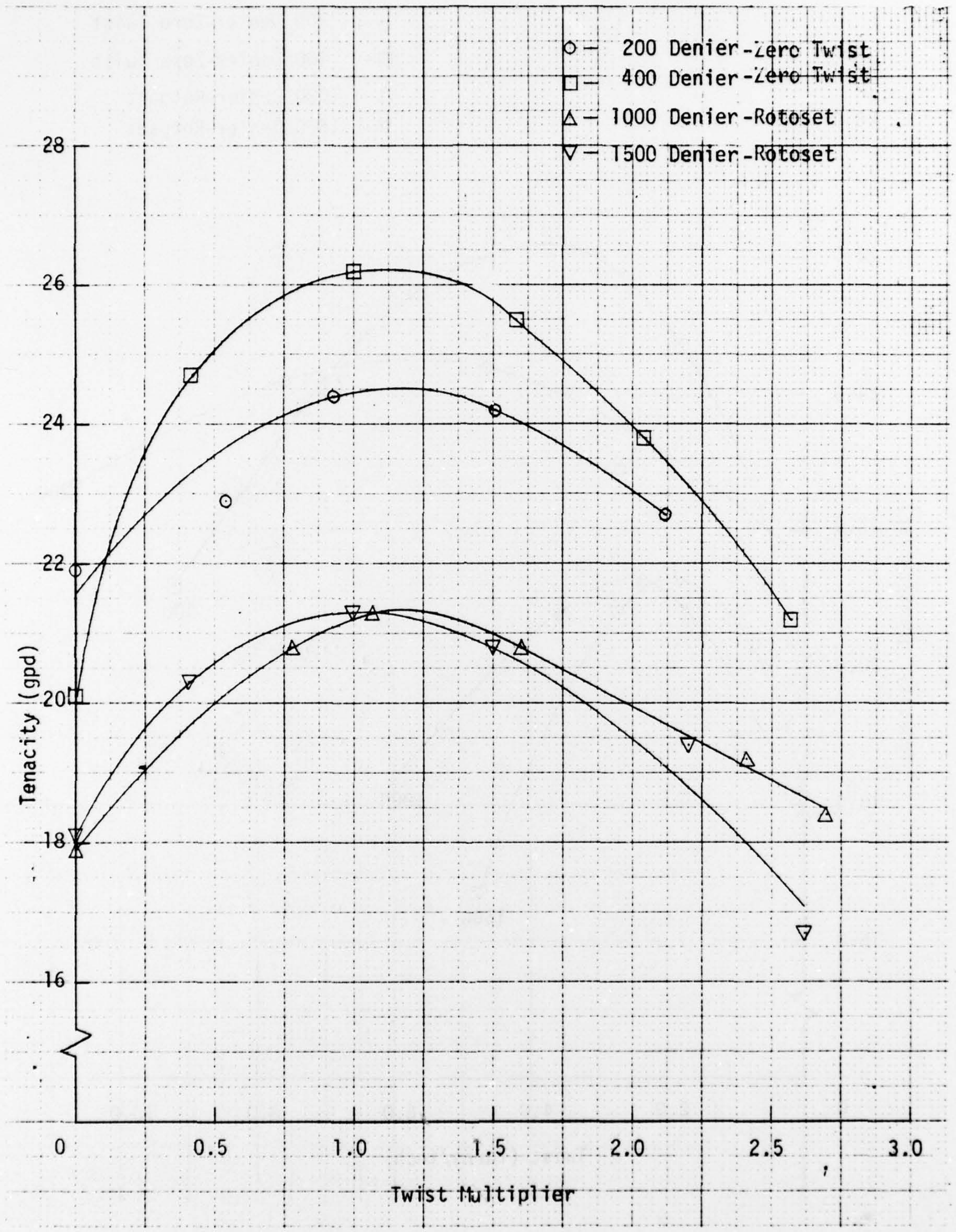


Figure 2. Rupture Tenacity as a Function of Twist Multiplier for Four Kevlar 29 Yarns

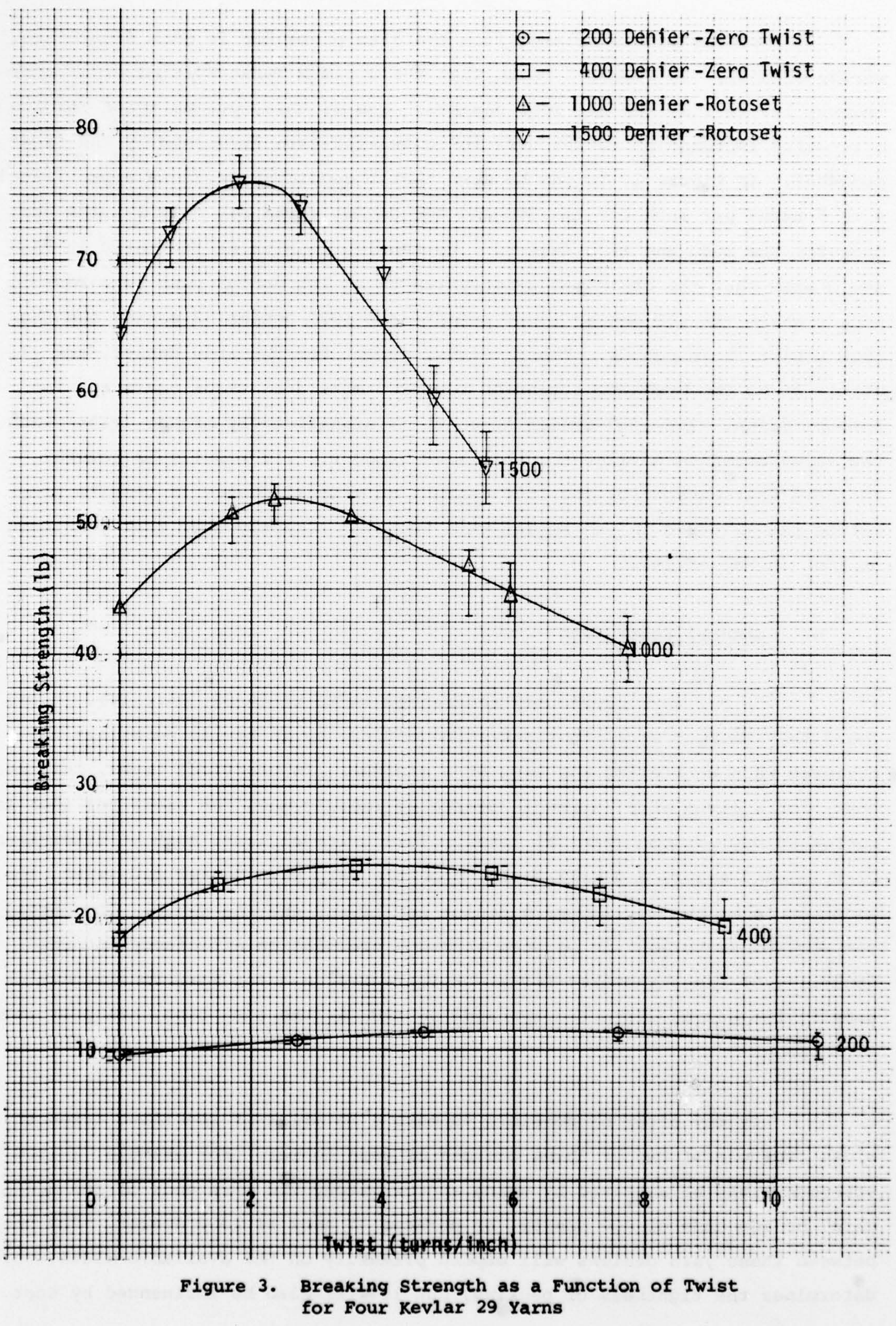


Figure 3. Breaking Strength as a Function of Twist for Four Kevlar 29 Yarns

Several points arising from the data presented in each figure are worthy of note. In Figure 2, note that the optimum Twist Multiplier is approximately 1.0 to 1.25 for all four deniers. Use of this optimum twist results in a tenacity increase of 20-25% over the untwisted yarn furnished by the fiber producer. In Figure 1, it can be seen that the optimum twist is approximately 4 to 6 turns per inch for the 200 and 400 denier yarns but only 2 turns per inch for the 1000 and 1500 denier. The tensile results as presented in Figure 3 show that the otpimized twist strength of 200 denier yarn is almost 11 pounds while the 400 denier is 24 pounds, the 1000 denier 52 pounds and the 1500 denier is 76 pounds. These values, except for the 1500 denier, are all within 5% of the breaking strengths measured more than three years ago for Rotoset yarns. The 1500 denier strength is significantly higher (+15%) than the value obtained earlier for this same product. The results in general indicate that except for the 1500 denier, no radical change in tensile properties has occurred in the Kevlar yarn received recently over that furnished by Du Pont in May of 1974.

B. General Restraints

In the work previously referenced (AFML-TR-74-65, Part IV), it was found that maximum strength translation efficiency in Kevlar materials was achieved when warp crimp was kept at a minimum. In practical terms, this means that, for a given warp, strength decreases rapidly when the picks per inch are increased beyond some critical level. This critical limit must be determined by trial and error, and will depend upon the warp yarn denier and twist, the ends per inch, the filling yarn denier and twist, and the weave. In general, a compromise has to be made between strength translation efficiency and the stability of the structure, for a structure designed for maximum strength is usually too easily distorted by handling and, at the same time, has poor seam efficiency.

It may often be possible to make a material of specified strength and width from one of two or three choices of yarn denier. For example, a 1500 lb strength might be achieved by using approximately 200 warp ends of 200 denier yarn, or 100 ends of 400 denier, or perhaps 35 ends of 1000 denier. The choice between these yarn deniers will depend primarily on the available width, which determines the tightness of packing, but it will also be influenced by cost.

Current Kevlar yarn prices range from \$8.50/lb for 1500 denier to \$22.50/lb for 200 denier, and since strength is roughly proportional to weight regardless of the denier, it is always cheaper to use a high denier yarn to achieve a given strength. Moreover, weaving is faster, easier and, therefore, cheaper with higher deniers. In our previous work, cost reduction was usually the determining factor when a choice was available. In the present work, development of a structure having good joint efficiency was the overriding factor, and this usually required that the lower denier yarn be selected.

Yarn twist is another factor which must be specified in any design. In our previous work, yarn twist was found to have a large influence on yarn strength, and all structures were designed using the optimum twist level in the warp yarns, for it was felt that this should lead to the lowest possible fabric strength/weight index. Since that work was done, it has been found that this is not necessarily the case. Lower twist yarns can flatten out more in the structure, resulting in a lower crimp amplitude than higher twist yarns would have in the same structure. Thus, strength translation efficiencies may be higher, tending to offset the fact that the yarns themselves may be weaker. Moreover, low twist yarns fill the structure better, resulting in a possible increase in seam efficiency.

Because of these considerations, after many preliminary designs had been achieved using high twist warp yarns, emphasis was shifted to low denier, low twist yarns because it was felt that this would lead to designs having the best combination of the important properties, namely high strength/weight index, high joint efficiency, and good resistance to distortion.

C. Choice of Yarn Denier

Yarns are supplied by the manufacturer in certain specific sizes, designated by the "denier," which is the weight in grams of 9000 meters of yarn. In the case of Kevlar 29, the available deniers are 200, 400, 1000 and 1500. These, along with heavier yarns made by plying (twisting) multiple ends of singles together, form the discrete units from which all fabric strength/width combinations must be made.

During the course of this work, the manufacturer of Kevlar yarns, E. I. du Pont de Nemours and Co. modified the structure of their 200 and 400 denier yarns. Initially these had been supplied as Rotoset yarns, in which the filaments are lightly entangled at periodic intervals to provide cohesion to the assembly. Currently, these yarns are being supplied without the use of Rotoset, and the cohesion results from a very low level (less than 0.5 tpi) of twist, called producer's twist. The heavier yarns, 1000 and 1500 denier, are still Rotoset. Most of the narrow fabric constructions described herein were made with Rotoset yarns. The two canopy fabrics were made with non-Rotoset yarns. It is likely that the narrow fabric constructions can be used successfully with non-Rotoset yarns, though this has not been verified for all constructions. The canopy fabric constructions are specific for non-Rotoset yarns, for it was found that constructions previously developed using Rotoset yarns gave excessively low values of air permeability when made with non-Rotoset yarns.

The strength of a fabric is determined by the number of load-bearing yarns which it contains per unit width, and the effective strength of these yarns as they lie in the fabric. A strength of 1500 lb per inch of width, for example, might be achieved by using 200 ends of 200 denier yarn (7.5 lb/end), 100 ends of 400 denier yarn (15 lb/end), or 43 ends of 1000 denier yarn (35 lb/end), all containing optimum twist, and assuming a 70% strength translation efficiency. The choice between these alternatives depends on the desired tightness of yarn packing in the fabric, for although the strength of a yarn varies approximately as the denier, its width varies approximately as the square root of the denier. Thus, 200 ends of 200 denier yarn will be packed more tightly in 1 inch of width than 100 ends of 400 denier yarn, and 43 ends of 1000 denier yarn will be even less tightly packed.

The tightness with which the yarns in a fabric are packed depends upon the number of yarns per inch and the effective width of the yarns as they lie in the fabric. Kevlar yarns as supplied by the manufacturer (designated herein as "0 twist") are ribbon-like in cross section. Twisting tends to change their cross-section towards the circular. In order to obtain an estimate of the effective width of yarns of various deniers and twists, yarns were twisted to various levels using a standard twisting frame set up to run under

normal commercial conditions. The twisted yarns were then wound under low tension on an 8" x 10" card using a seriplane winder. The tension used, though low, was sufficient to bend the card, so that the yarns were in contact with the card on one side, and totally unsupported on the other. This gave an opportunity to measure the extent to which each yarn could be flattened by low normal pressure of the sort that could exist at the yarn intersections in a woven fabric. Thus, in Table 2, dimensions are given for "unsupported" and "supported" widths. It is believed that the supported widths are more pertinent for representing the yarn in a woven fabric, and these have been used in all calculations of available space factors.

The addition of twist quickly reduces the width of the yarn to a minimum value which remains essentially constant for all twist levels and whether the yarn is supported or unsupported. This has occurred at 4 tpi for the 200 denier yarn, 3 tpi for 400 denier, 2 tpi for 1000 and, presumably, also 1500 denier yarn. The supported width of the 200 denier yarn containing 1 tpi of twist is essentially the same as that of the untwisted yarn. Coincidentally, the supported width of the 1 tpi, 400 denier yarn is the same as the 200 denier yarn. For the higher deniers, 1 tpi of twist has been enough to consolidate the yarn structure, as evidenced by the small difference between unsupported and supported widths. This is because the helix angle increases approximately in proportion to the square root of the denier at low twist levels.

An estimate of the packing tightness can be obtained from the values of yarn width given in Table 2. If 200 ends of 200 denier yarn containing optimum twist were laid side by side so that they were touching, but not compressed, they would occupy a width of 200 x 0.012" = 2.40". If they were compressed to a 1" width, their individual widths would have to be reduced to a factor of 1/2.40 = 0.42. (This makes no allowance for additional compression caused by the interlaced filling yarns.) We shall call this factor the "Available Space Factor," or ASF. Similar calculations for the 400 denier and 1000 denier yarns give ASF values of 0.67 and 1.16 respectively.

An analysis of warp ASF values for the Kevlar 29 materials already designed gave the distribution given in Table 4.

TABLE 2

EFFECTIVE WIDTHS OF TWISTED ROTOSET KEVLAR YARNS

Twist	Yarn Width (mil)							
	200 denier		400 denier		1000 denier		1500 denier	
(tpi)	unsupported	supported	unsupported	supported	unsupported	supported	unsupported	supported
0	10.4	11.3	13.0	19.0	22.0	29.9	29.4	43.0
1	7.5	11.0	9.6	11.1	16.0	16.8	18.5	19.9
2	6.4	6.5	--	--	14.1	14.1	--	--
3	--	--	8.8	8.5	--	--	17.2	16.7
4	6.1	6.0	--	--	13.6	13.9	--	--
5	--	--	8.5	8.8	--	--	16.0	17.4
6	6.1	6.2	--	--	12.8	13.9	--	--
7	--	--	8.0	8.3	--	--	--	--
8	5.5	5.9	--	--	--	--	--	--
10	6.0	6.0	--	--	--	--	--	--

The underlined values are for optimum twist levels.

TABLE 3

STRENGTH AND DIMENSIONS OF ROTOSET KEVLAR YARNS

	Strength (lb)				Width (mil)		Thickness (mil)	
	Zero Twist		Optimum Twist					
Denier	Actual	70% of Actual	Actual	70% of Actual	Zero Twist	Optimum Twist	Zero Twist	Optimum Twist
200	9.4	6.5	10.7	7.5	11	6	2.5	5.0
400	18	13	22	15	19	9	2.5	5.0
1000	42	29	50	35	30	14	2.5	8.5
1500	53	37	65	45	43	17	4.0	9.0
1000/2	--	--	100	70	--	24	---	8.0
1500/2	--	--	140	100	--	31	---	10.5
1500/3	--	--	200	140	--	35	---	11.0
1500/4	--	--	265	185	--	45	---	15.5
1500/5	--	--	300	230	--	62	---	17.0
1500/6	--	--	400	280	--	63	---	19.0

TABLE 4

DISTRIBUTION OF WARP AND FILLING AVAILABLE SPACE FACTORS IN KEVLAR 29 MATERIALS

ASF	Number of Materials: Warp	Filling	WASF +FASF
0-0.19	1	0	0
0.2-0.39	10	0	0
0.4-0.59	7	0	0
0.6-0.79	9	1	0
0.8-0.99	8	4	0
1.0-1.19	9	10	0
1.2-1.39	4	9	0
1.4-1.59	1	5	1
1.6-1.79	0	5	8
1.8-1.99	0	7	14
2.0-2.19	1	3	4
2.2-2.39	0	3	9
2.4-2.59	1	0	6
2.6-2.79	0	0	2
2.8-2.99	0	0	2
3.0-3.19	0	0	2
ASF Mean Value	0.82	1.48	2.15
ASF Standard Deviation	0.51	0.42	0.39

In general, the stronger materials (lb/inch) have low WASF values and the weaker have high values, as would be expected. When possible, it seems desirable to keep the WASF between about 0.5 and 1.2. In the above example, it is likely that the 400 denier warp at a WASF of 0.67 would give the most balanced, stable fabric, though the 1000 denier warp at a WASF of 1.16 might also be used.

From the data in Table 2 and calculations similar to those illustrated in the above example, it is possible to plot the strength* (lb/inch) WASF relationship for all yarn deniers, both at zero twist and at optimum twist. The results of such calculations are plotted in Figures 4 and 5.

*Assuming 70% translation efficiency.

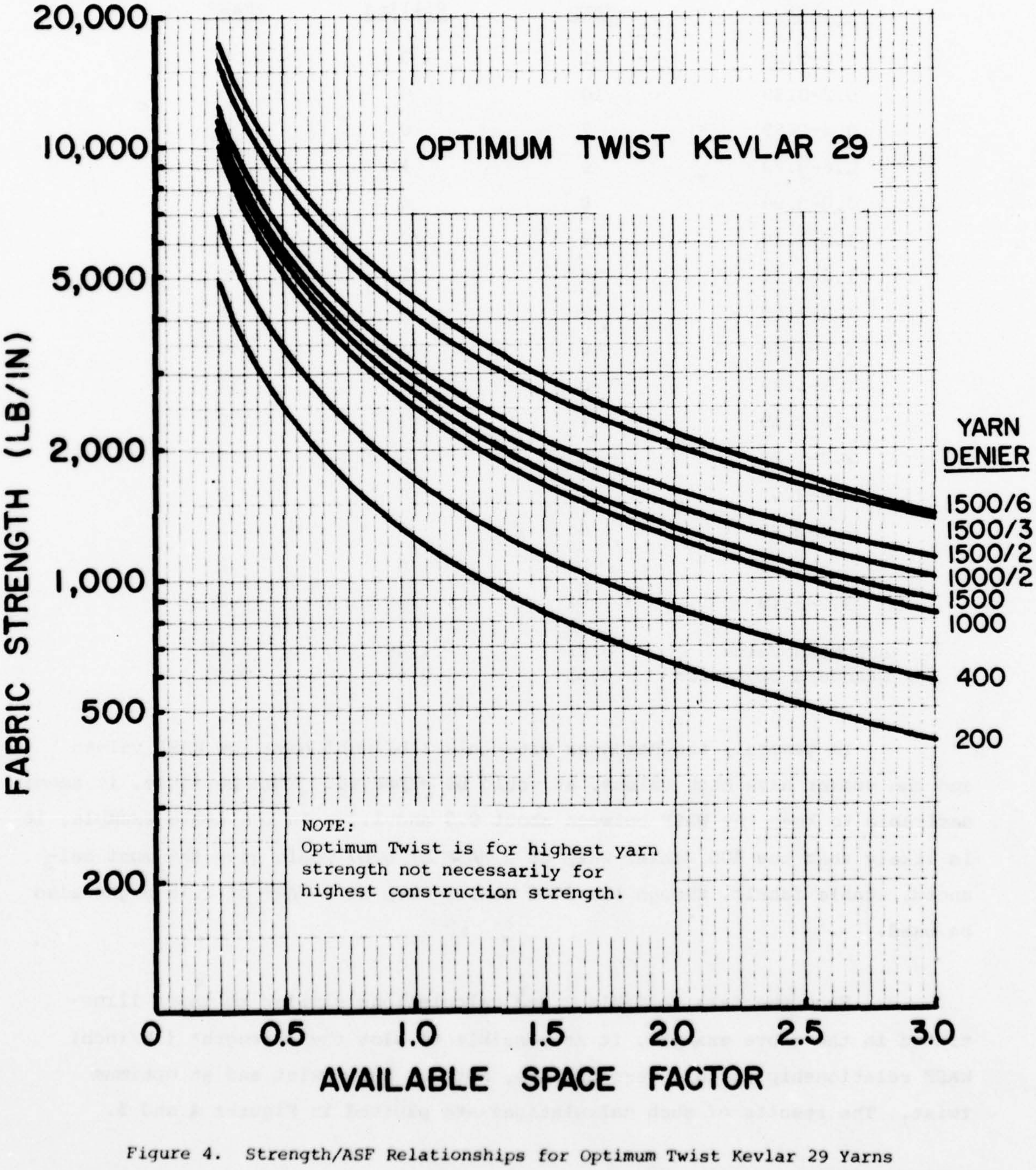


Figure 4. Strength/ASF Relationships for Optimum Twist Kevlar 29 Yarns

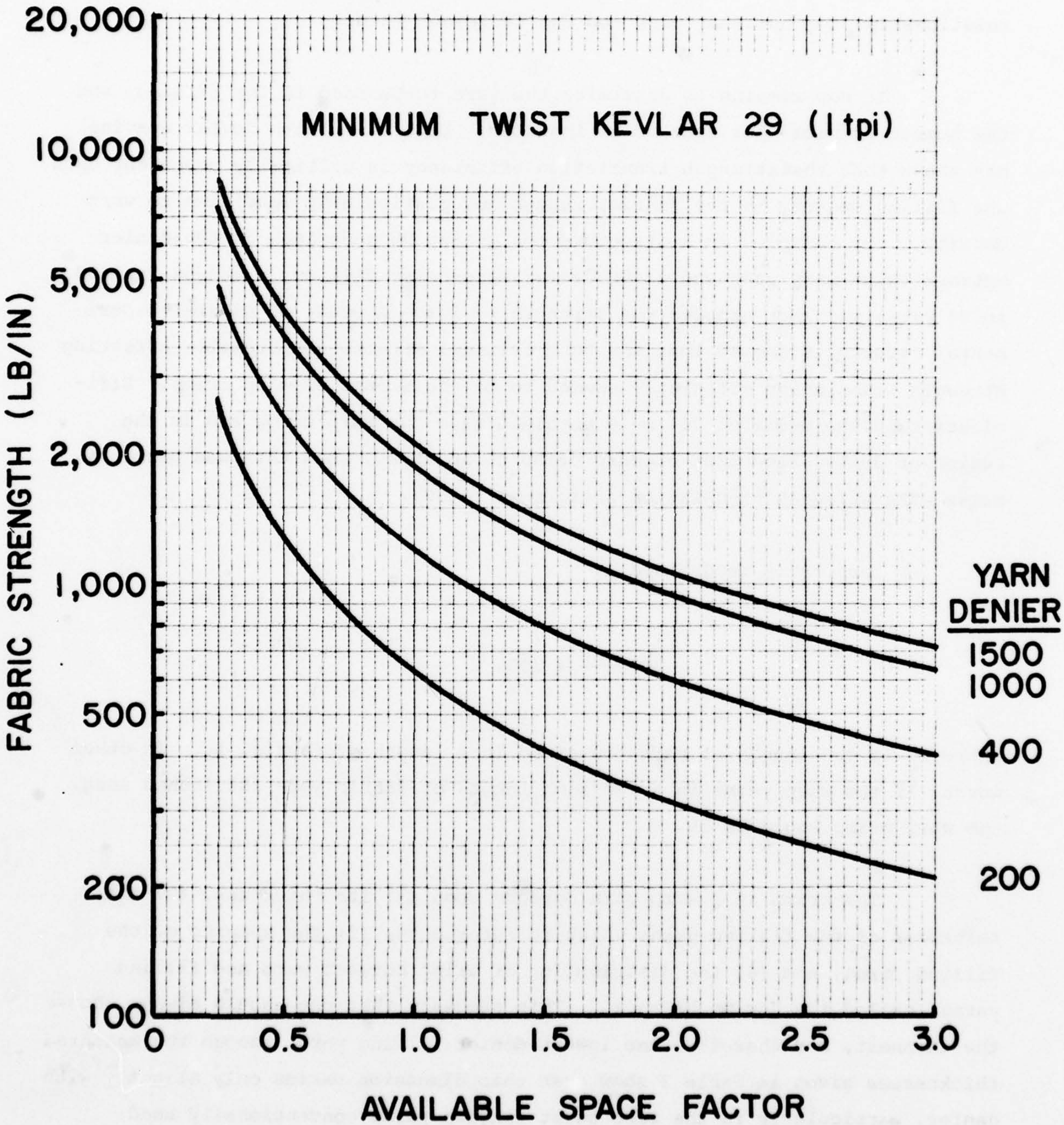


Figure 5. Strength/ASF Relationships for Minimum Twist Kevlar 29 Yarns

This plot now permits us to select the most appropriate yarn denier for any desired strength per unit width, so as to obtain a structure having a reasonable woven tightness. The data in Table 2 also permits us to convert from an ASF value to ends per inch for any given yarn denier, by the type of calculation illustrated in the example. Figures 6 and 7 are plots of these relationships for optimum twist and "as recieved" yarns.

It now remains to determine the yarn to be used in the filling, and the number of picks per inch to be inserted. Experience with Kevlar weaving has shown that the strength translation efficiency is critically dependent upon the filling density in the fabric, though not particularly sensitive to warp density. For example, in a structure containing 96 ends/inch of 400 denier optimum twist warp yarn and a 400 denier zero-twist filling, a change from 32 to 34 picks per inch dropped the strength by 10%. A study of several experimental structures showed that the most critical structural parameter affecting strength translation efficiency seemed to be the amount of warp crimp. Efficiencies in the order of 70% were obtained when the warp crimp was in the region of 3-4%. Reduction of warp crimp to about 2%, when this was possible, raised the strength translation efficiency to 80%.

Yarn crimp is defined as

$$\frac{l_y - l_f}{l_f} \times 100\%$$

where l_y is the length of yarn contained in a length of fabric, l_f. In other words, if the warp yarns in a 100-inch length of fabric were 103 inches long, the warp crimp would be 3%.

The crimp in a warp yarn depends upon (1) its thickness, (2) the thickness of the filling yarns which it intersects, (3) the spacing of the filling yarns, and (4) the distribution of crimp between warp and filling yarns, called the "crimp balance." This suggests that one should always choose the thinnest, and therefore the lowest denier filling yarn, though the measured thicknesses given in Table 2 show that this dimension varies only slightly with denier, particularly in the zero twist singles yarns conventionally used

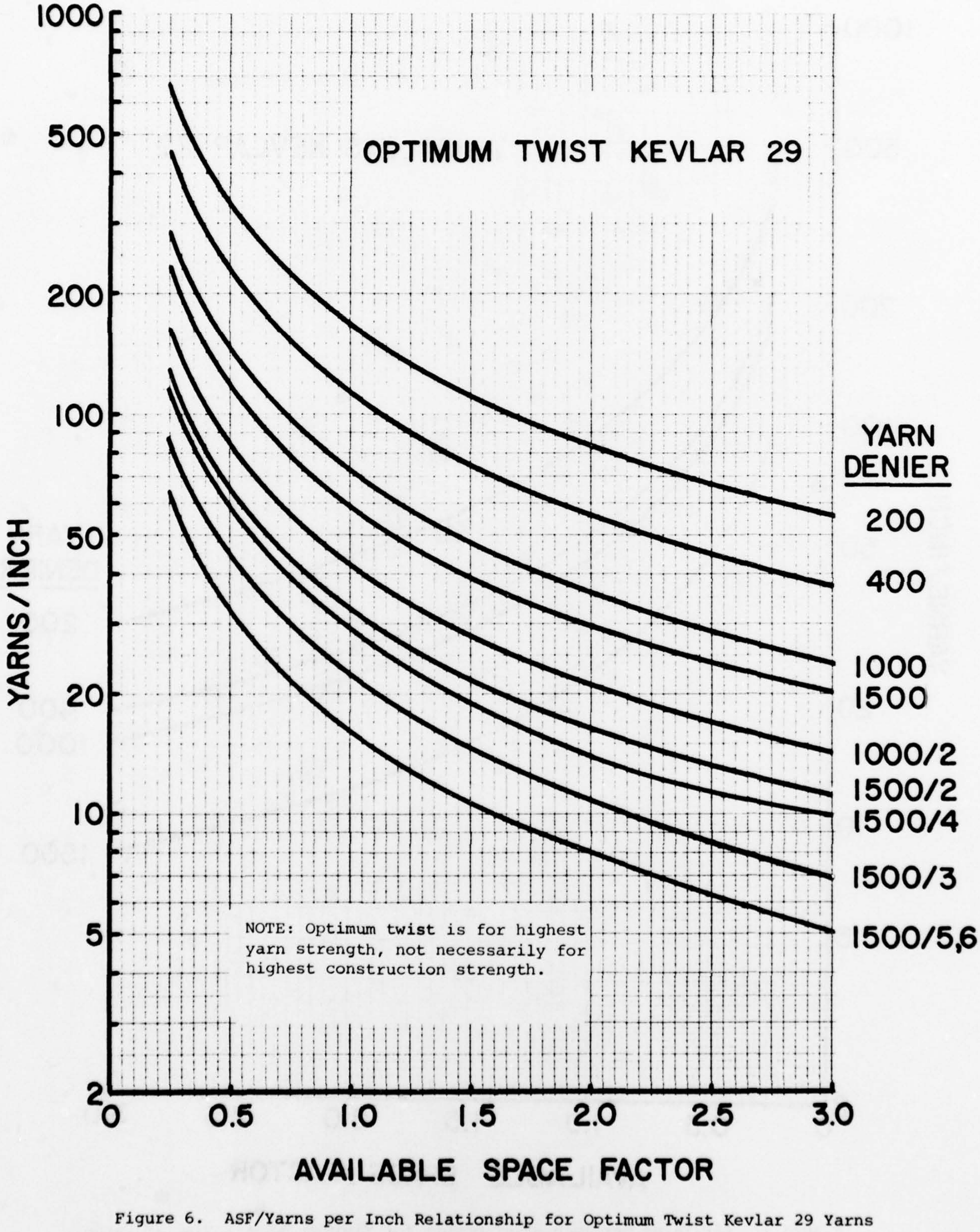


Figure 6. ASF/Yarns per Inch Relationship for Optimum Twist Kevlar 29 Yarns

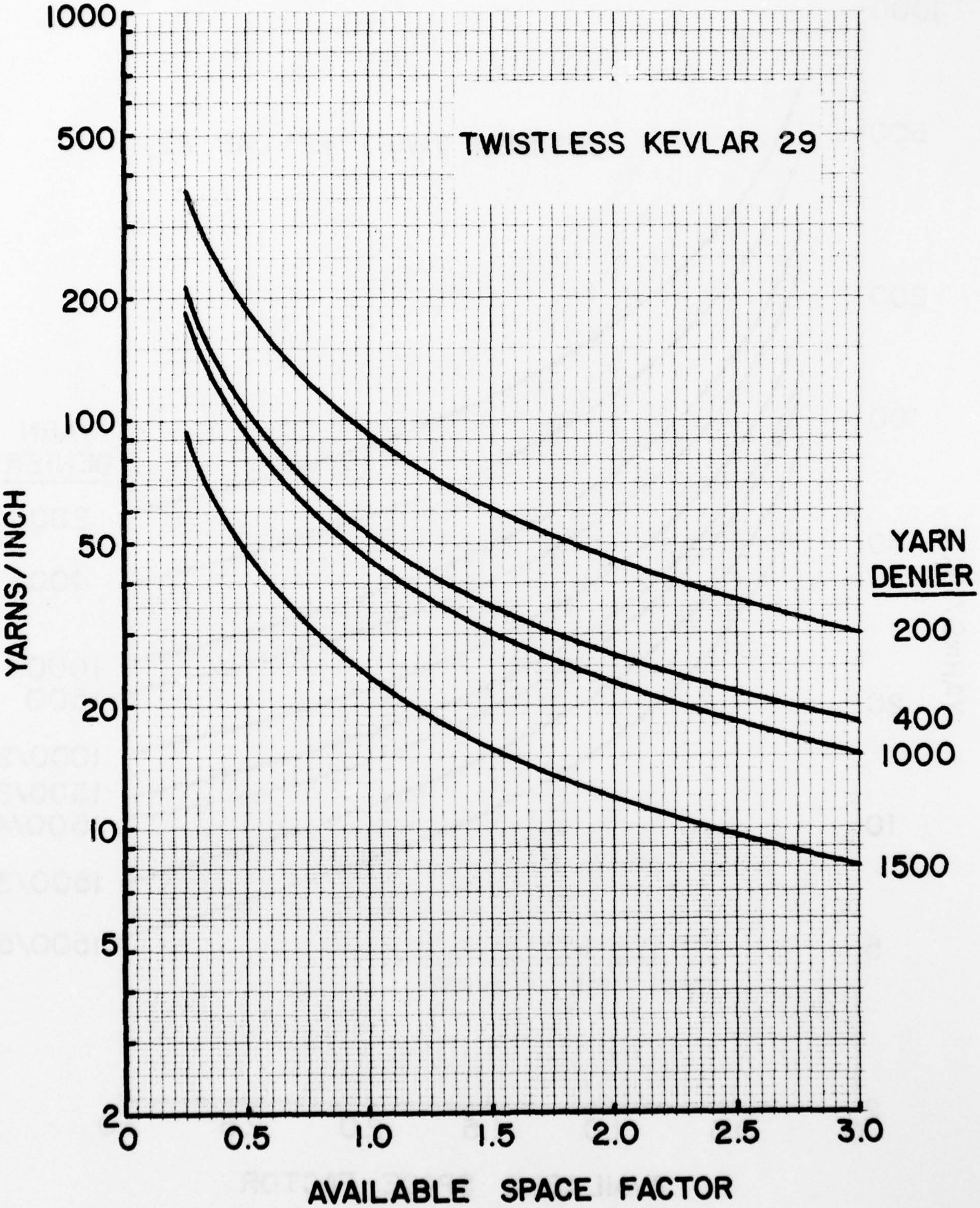


Figure 7. ASF/Yarns per Inch Relationship for Minimum Twist Kevlar 29 Yarns

in fillings. The most important variable, then, is probably filling yarn spacing, which could be represented by a Filling Available Space Factor (FASF), corresponding to the WASF discussed previously.

The frequency distribution of these FASF values is given in Table 4. As would be anticipated, these values tend to be higher than those for the warp, for the sole criterion determining the density of packing of the filling was to maintain a strength translation efficiency of 70% or higher, consistent with the production of a reasonably stable woven structure. In general, the lower values of WASF required a higher value of FASF, so that the sum of these two values, given in the last column of Table 4, has a frequency distribution which is concentrated within a fairly narrow range.

It is possible, therefore, that selection of a warp yarn to give a WASF within the range 0.5-1.2, and a filling yarn and pickspacing to give an FASF such that the sum (WASF+FASF) lies in the range 1.6-2.4, could provide an intelligent approach to design of a new material, or to improvement of an old design. In the end, since our experience has shown Kevlar to behave in unexpected and seemingly unpredictable ways, the optimum design will have to be worked out on the loom by varying such parameters as picks per inch, type of weave, and, perhaps, warp yarn denier and ends per inch.

Verification of the usefulness of the approach outlined above was obtained by comparing designs predicted in this way with the constructions of 51 materials actually produced during a previous contract. In this comparison, 23 of the predicted warp constructions were essentially identical to those produced, 17 were very close, and 11 were significantly different. In the filling, 24 were essentially identical, 11 close and 16 different. The differences were mainly concerned with selection of the yarn denier. The approach using the plots in Figure 4 indicated that most of these materials could have been made firmer by selection of a finer (and, therefore, more expensive) warp yarn. It would be interesting to remake these materials to see whether the predicted construction would indeed be firmer and as efficient as that actually produced.

It remained to verify the applicability of this approach to the design of new fabrics, and this was tested during the development of the

materials described herein. Unfortunately, it proved to be less useful than was hoped. It can be used to provide a rough guide to which constructions will be weavable, and which will be either extremely open or very tight. But any competent weave designer having had some experience with Kevlar fabrics will know this without the use of design tables and graphs. In fact, when all of the new designs described in this report are analyzed, it is found that the average values of WASF and FASF are significantly higher than those given in Table 4 (WASF averaged 1.9 instead of 0.8; FASF averaged 2.3 instead of 1.5). This may be due to a higher preponderance of low strength fabrics in the new materials, but it emphasizes the fact that orderly design approaches such as the one described often can be used as guides for conventional textile fibers, but are of limited help when structures are being made from Kevlar under restraints for optimization such as were imposed on the work described herein.

It is important also to realize that the minimum strength and weight obtainable from a usable Kevlar fabric is determined by the minimum available yarn denier. At the present time, this minimum denier is 200, and the lowest strength which can be achieved in a fabric is about 200 lb/inch, at a weight corresponding to about 2.0 oz/yd^2 (0.06 oz/yd/inch width).

D. Design Steps

In general, therefore, the approach to establishing a suitable design for any particular material involves the following steps:

1. Select a warp yarn denier most likely to result in a suitable structure packing for the strength and width desired. This will seldom be an unequivocal choice, but will be influenced by experience and judgment. In general, fabrics having a strength of less than 1000 lb/in. will be likely to use a 200 denier yarn in the warp. Fabrics from 1000 to 2000 lb/in. will probably have a 400 denier warp. And fabrics over 2000 lb/in. will use either 1000 or 1500 denier, or multiples of these in the form of plied yarns. Exceptions to these guidelines arise frequently however, because of special requirements or problems arising in a particular structure.

2. Based on the strength of the warp yarn selected, and assuming a 70-75% strength translation efficiency, calculate the number of ends needed to obtain the desired strength.

3. Using either Rotoset or zero twist (producer's twist) yarn, set up a suitable warp using low twist (1-2 tpi) yarns and select an appropriate filling yarn, usually of the same denier or smaller than the warp yarn. Do not twist the filling yarn.

4. By a series of weaving and tensile testing steps, determine the maximum number of picks per inch which will give the highest attainable strength consistent with an acceptable level of structural stability.

5. If the strength achieved is higher than required (breaking strength should be 10% over the specified rated strength), try reducing the number of warp ends to bring both the strength and weight down. (Note: Occasionally reducing the number of ends will not affect the strength, or may even increase it. This is because [1] the increase in warp yarn mobility has increased its strength translation efficiency or [2] the weaving tensions are more uniform, or [3] for reasons often unknown and certainly unpredictable.)

6. When a suitable tentative design has been worked out, weave a sufficient quantity to be sure that the design is easily weavable, reproducible, and to verify that the strength is adequate.

7. Check the joint strength utilizing applicable fabricated joint samples. If this is inadequate, consider an alternative design which may have to be tighter even though the strength translation efficiency may be somewhat lower, or consider the possible use of a coating to better stabilize the structure.

E. Weaving Precautions

The first step in a weaving operation is to wind a parallel array of uniformly tensioned warp yarns onto a cylindrical warp beam (see Figure 8). This is then mounted on the back of the loom, and each warp end drawn through the eye of a heddle which is carried on one of a number of movable frames called harnesses. Then it passes through a slot, called a dent, in a comb-like structure called a reed, and then around the take-up roll to be attached to the cloth beam. The threading of the warp ends through the loom in this way is called the drawing-in operation. The warp is tensioned by applying a braking torque to the warp beam.

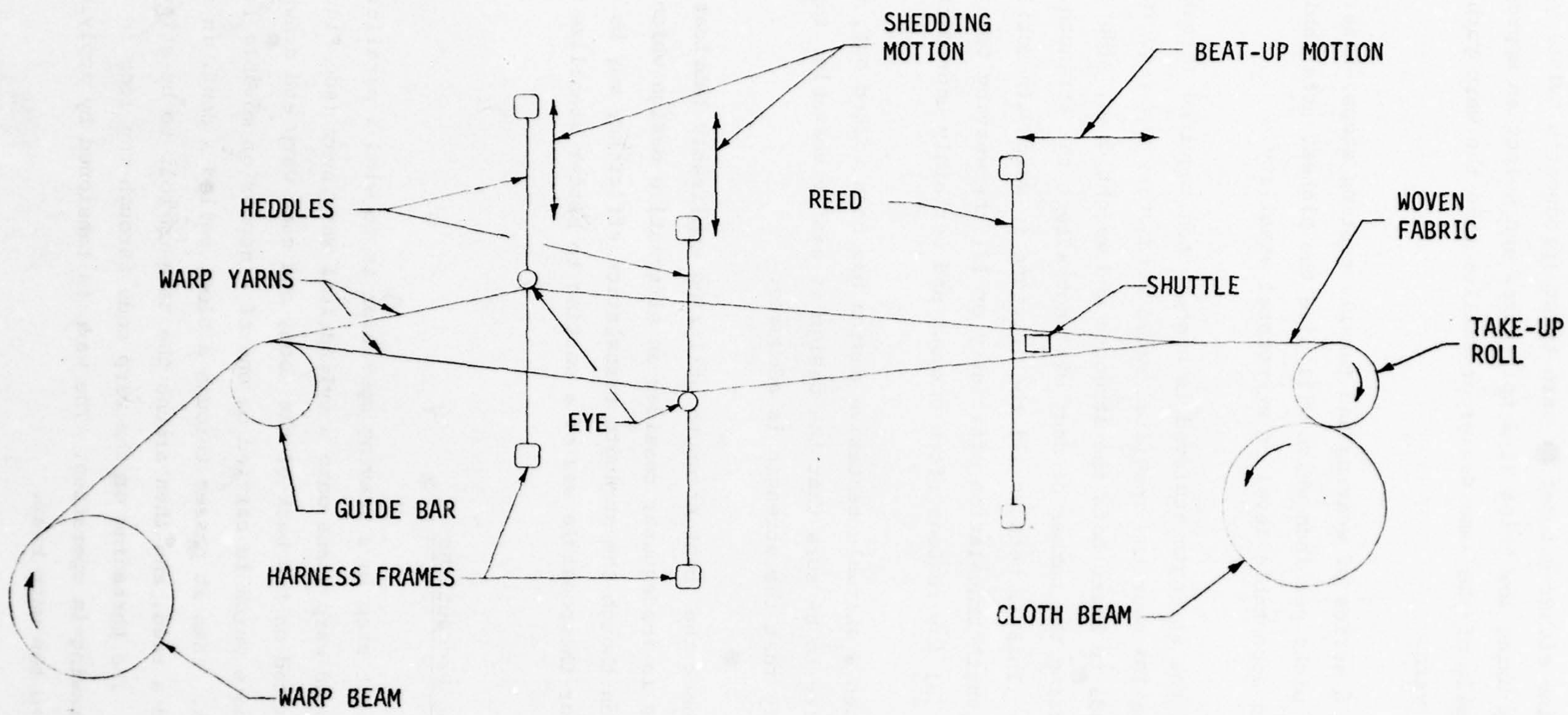


Figure 8. Schematic Representation of a Loom

Appropriate vertical motion of the harnesses ("shedding") separates the warp yarns into two arrays, forming a so-called shed through which the shuttle carrying the filling yarn is passed ("picking"). Horizontal motion of the reed, the beat-up, then pushes the inserted filling yarn tightly against the woven cloth ("beating"). The shed then changes, as determined by the weave pattern, and the operation is repeated.

Because of Kevlar's high tensile modulus and low elongation, it cannot be handled in the loom like a conventional textile fiber. Yarn tensions must be carefully controlled, and kept uniform through the stress cycles imposed by shedding, picking and beating. Warp beams should be no more than 1/2 inch wider than the woven product. Loom adjustments must be made carefully to maintain precise timing of the various actions, proper alignment and freedom from intermittent irregularities resulting from worn or improperly adjusted moving parts. Additional warp tension may have to be provided. It is most important to be sure that all warp yarns are under the same tension. This will require unusually precise control of loom adjustments. All contact surfaces must be highly polished or covered with Teflon tape. The use of sand rolls should be avoided, particularly with finer materials such as ribbons. Particular attention must be given to keeping heddle eyes and reeds in perfect condition, free from rust and any rough or sharp edges. It is sometimes helpful to use Teflon coated heddles. Teflon coating the reed has not been found to be desirable because rubbing of the yarn in the dents creates worn areas which become rough. Special care must be taken to avoid tight selvages (cloth edges) which, particularly in ribbons, cause premature tensile failure at loads which may be as low as one-quarter the design strength.

Kevlar is very susceptible to snagging or rubbing on rough surfaces. The excessive accumulation of a white, powdery deposit on any guides or other surfaces contacted by the yarn at any stage of processing (winding, twisting, warping, weaving) is an indication that machine adjustments are needed. Such deposits result from fibrillation of the fiber surface (i.e., an action breaking up individual fibers into tiny component strands called fibrils, to which Kevlar is particularly prone), and can be largely eliminated if appropriate care is taken. Excessive fibrillation of the fiber surface results in a "hairy" appearance in the fabric, which may result in a loss in strength.

The woven fabric should be carefully inspected for defects which are the result of accidents or inadequate attention to protecting the yarns through the rather severe handling to which they are subjected. Such defects show up, for example, as nonuniformities or actual mistakes in the weave pattern itself; warp direction streakiness, or ripples parallel to the warp indicating a tight warp end; uneven selvages, evidenced by a wavy edge or protruding loops of filling yarn; local or overall surface fuzziness, indicating that the yarns have suffered excessive abrasive damage; axial curving of the fabric as a whole, resulting from a tension gradient across the band of warp yarns. Defects of this kind in Kevlar fabrics inevitably result in nonuniform warp yarn lengths which, in turn, cause premature breaks resulting in a reduced breaking load for the end item. Indeed, careful attention to the manner in which a specimen breaks in a tensile test will often reveal deficiencies in the weaving operation which can be corrected, giving a more uniform and, therefore, stronger material.

It should be emphasized that good weaving of Kevlar fabric is the result of a combination of appropriate loom settings and adjustments, combined with careful handling, and that probably there is no one correct way of achieving this end. Rather, a good Kevlar fabric will result from the concerned attention of an intelligent loom fixer and weaver to the task. With Kevlar, however, the lack of that concerned attention will almost certainly result in an unacceptable fabric.

An example of the many and varied problems which may be encountered in handling Kevlar yarns occurred early in the current work. As samples were being produced, it became obvious that some difficulties were being experienced in attaining the desired 75% minimum strength translational efficiency. Most of the ribbons were breaking nonuniformly across the width, i.e., breaking at one edge and then tearing. This type of failure necessarily results in a low tensile value since relatively few warp yarns are failing at one time. This is usually attributable to incorrect loom adjustment. With Kevlar, such adjustments are more critical than with most other organic fibers. Many changes were made in loom settings, warp preparation techniques and fabric designs in order to raise the translation efficiencies to acceptable levels (75% or better). A listing of the various samples prepared is shown in Appendix B, which illustrates the many attempts made to achieve the desired strength with certain of the ribbons.

After many weaving trials it was determined that many of the difficulties experienced which were being attributed to loom misadjustment were, in fact, related to tensile test technique. Early in the program it became apparent that Kevlar materials cannot necessarily be tested in the same way as their nylon counterparts. More care must be taken to avoid sharp bends, uneven stress distribution across the width of the fabric and, under some circumstances, fabric-to-fabric contact. In fact, the tensile testing conditions used for Kevlar materials appear to be so critical that it is always possible that the particular testing technique being used is causing premature breaks, and that the true strength of the material is higher than the measured strength. This is such an important point that FRL is now studying tensile testing of Kevlar materials under another Air Force contract (F33165-78-C-3406). The testing techniques used in the work described herein are outlined below. When the results of the study currently underway are available, it will be possible to evaluate the reliability of the current techniques. For the time being, they are believed to be satisfactory and are, in any case, the best presently known to us.

F. Tensile Testing

1. Instron Conditions

For all tests of Kevlar yarns or fabrics a free specimen length (between the jaws) of approximately 10 inches is used, with a crosshead speed of 1 inch/minute. When testing lighter weight materials better stress uniformity is sometimes achieved by bringing the load up to 10-15% of the anticipated breaking load, and stopping the Instron crosshead for 30 seconds before proceeding to rupture. This procedure is most effective with materials of widths in excess of 1-1/2 inch and strengths up to 8000 pounds, and has been used for such materials.

With narrow fabrics and braids, specimen elongation is determined by photographing two gauge marks on the specimen at predetermined load increments during the course of the test. The distance between the gauge marks at each load is read directly off the negative using a microfilm reader. (Note: Because of the tedious nature of the procedure, elongation was measured on only four representative materials. Load-elongation curves for these materials are given in Figures 14-17 and in Table VII.)

2. Specimen Grips

a. Yarn

The jaw system employed for all Kevlar yarn tensile testing is illustrated in Figure 9. The upper jaw is a pulley around which the yarn passes in a 180° arc. The lower component consists of a flat jaw, preceded by a semi-circular snubbing surface. Thus, two lengths of yarn are tested in parallel. Each length has 90° of wrap around the upper capstan and 180° of wrap around the lower. Since the strain distribution in the yarn is nonuniform at the capstan, the value of the true gauge length is not readily apparent and a method frequently described as "effective gauge length determination" is employed to compute a reliable set of gauge length corrections. (See AFML-TR-74-65, Part II.) Approximately ten yarn specimens are tested per sample. Tensile failure is usually observed in the free gauge length near but not on either the upper circular fixture or the lower moving jaw.

b. End Item

Ribbons and lighter weight webbings (up to 6000 lb rated tensile strength) are tested using a double-pin jaw of design supplied by the Air Force (see Figure 10a). The 3-foot long specimen is wrapped around the jaws as shown in the figure and a piece of heavy cotton duck inserted between the wraps over the outermost pins (top pin in top jaw, bottom pin in bottom jaw).

Broad fabrics are also tested on the double-pin jaws, by ravelling warp or filling direction specimens to a 1-inch width for a specimen length of three feet. At least three specimens are tested for each end item sample. Tensile failure usually is noted in the free gauge length at or near the point of first contact with the pin.

Braids and webbings are tested using four inch diameter split capstan jaws as shown in Federal Standard 191, Method 4108, and in Army Natick Laboratories Drawing No. 2-1-767. Webbings are wrapped around these jaws in the conventional way (see Figure 10b) requiring a specimen length of four feet. Braids were given one additional wrap for extra frictional restraint, and the tail protruding from the slot was knotted to inhibit slippage.

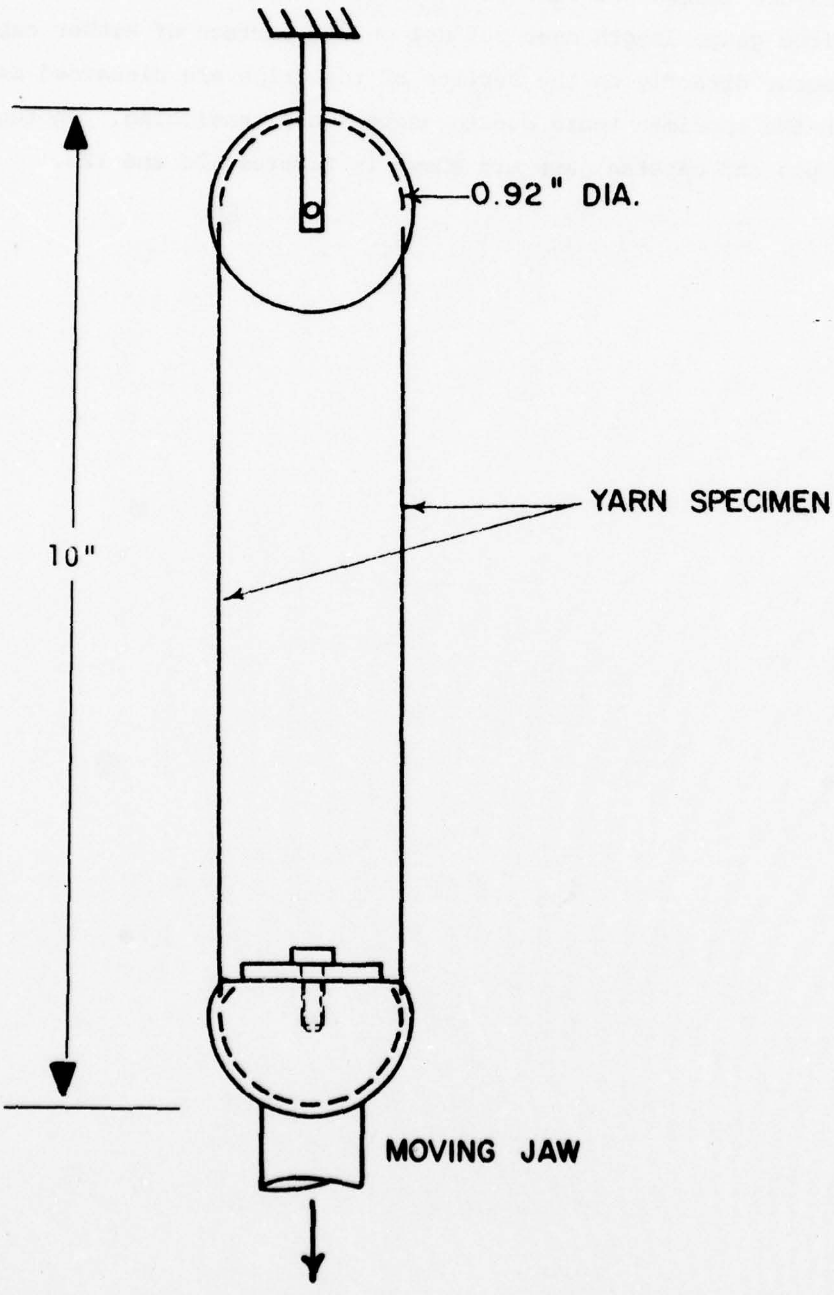


Figure 9. Yarn Tensile Test Configuration using Capstan Jaws

This increased the specimen length to six feet. In addition, for light braids (up to 3000 lb rated tensile strength) it was found advantageous to cross the second wrap over the first at the back of the jaws (see Figure 11). At least three specimens are tested per finalized design sample with failures usually noted in the free gauge length near but not on the surface of either capstan. Breaks which occur directly on the surface of the grips are discarded as are those in which the specimen tears due to uneven warp tensioning. Photographs of the double pin and capstan jaws are shown in Figures 12a and 12b.

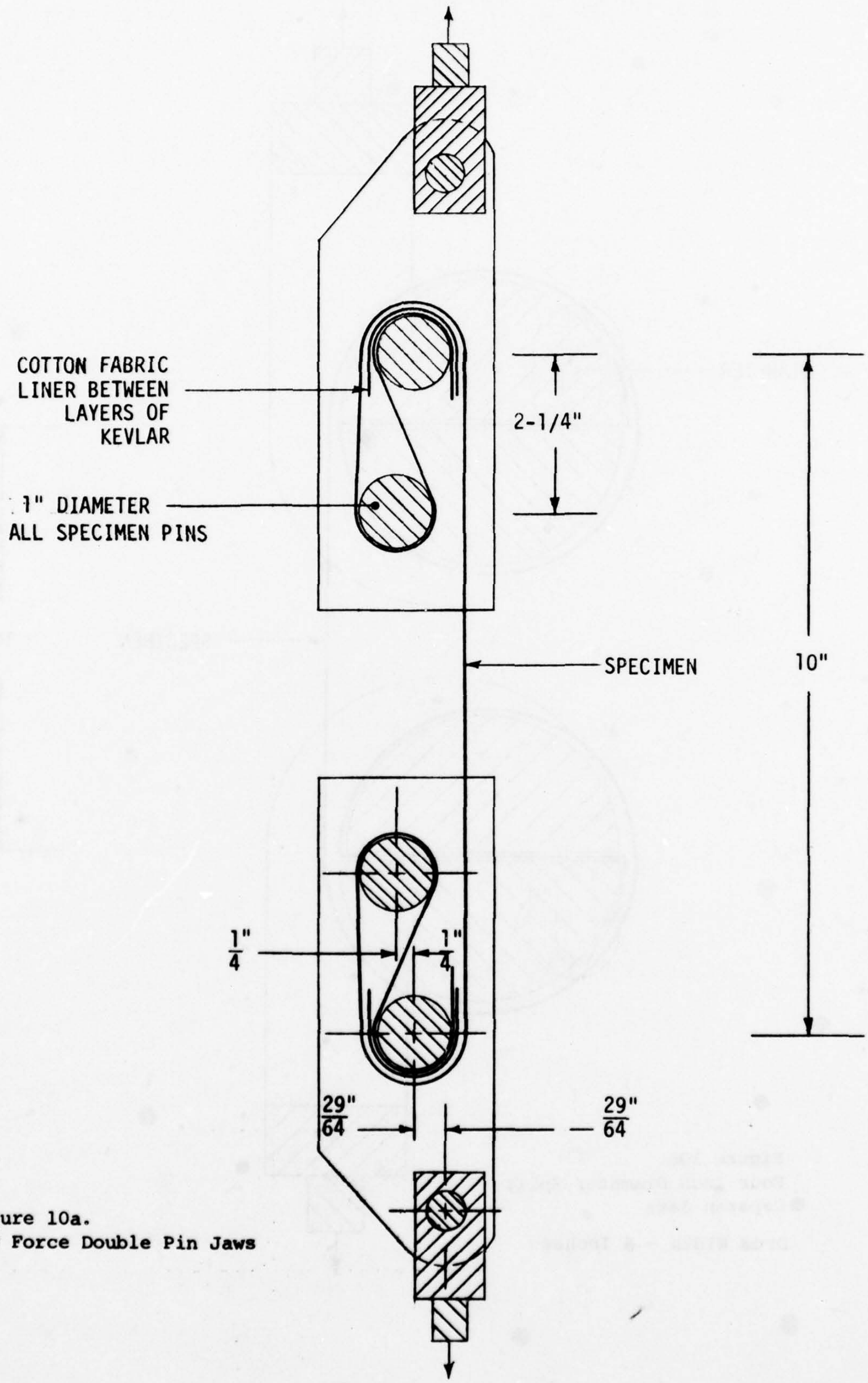


Figure 10a.
Air Force Double Pin Jaws

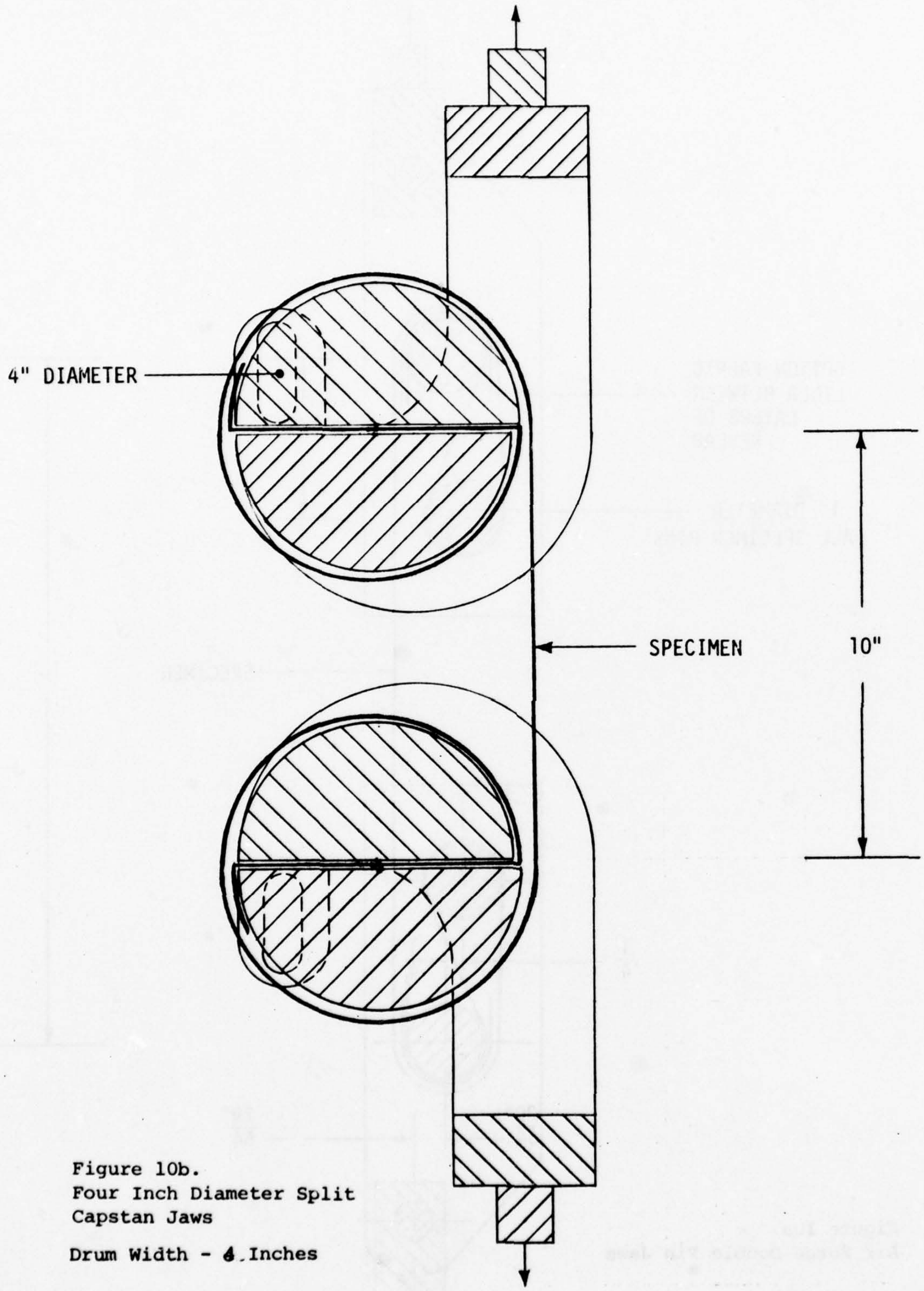


Figure 10b.
Four Inch Diameter Split
Capstan Jaws

Drum Width - 4 Inches

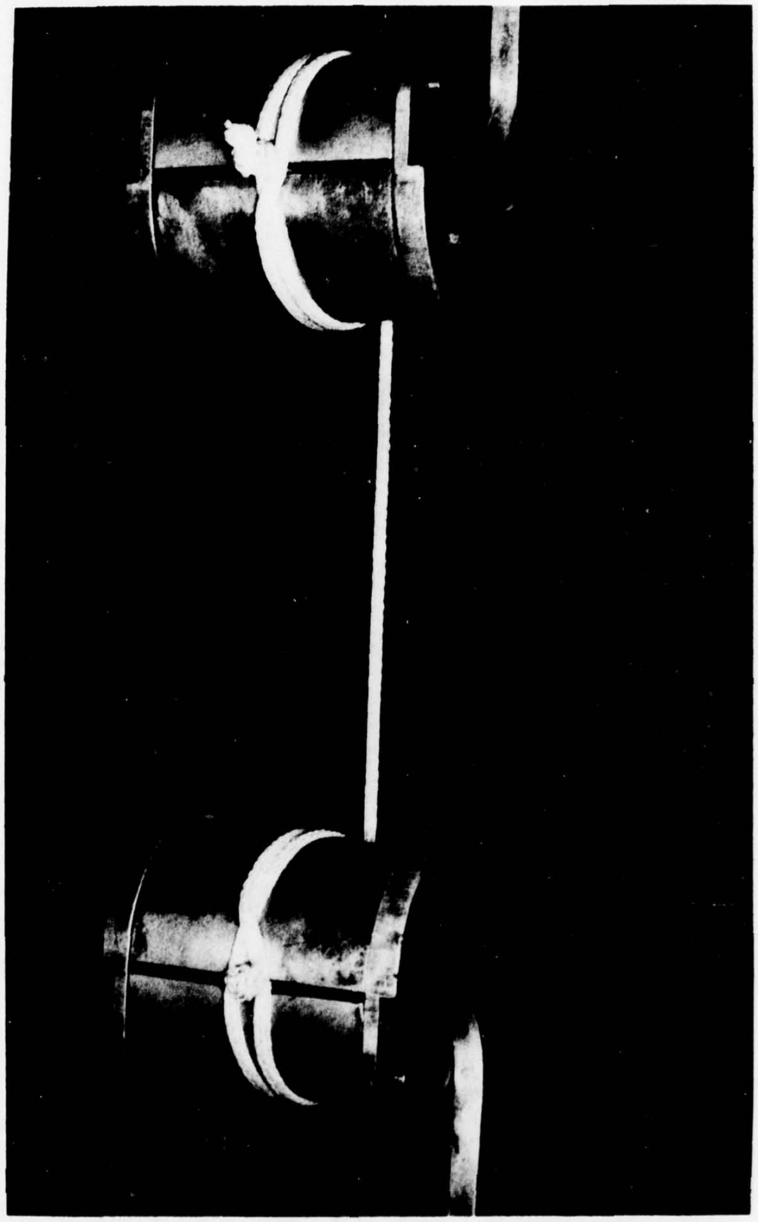


Figure 11. Photograph Illustrating Double Wrapping
with Cross of Braid on Capstan Jaws

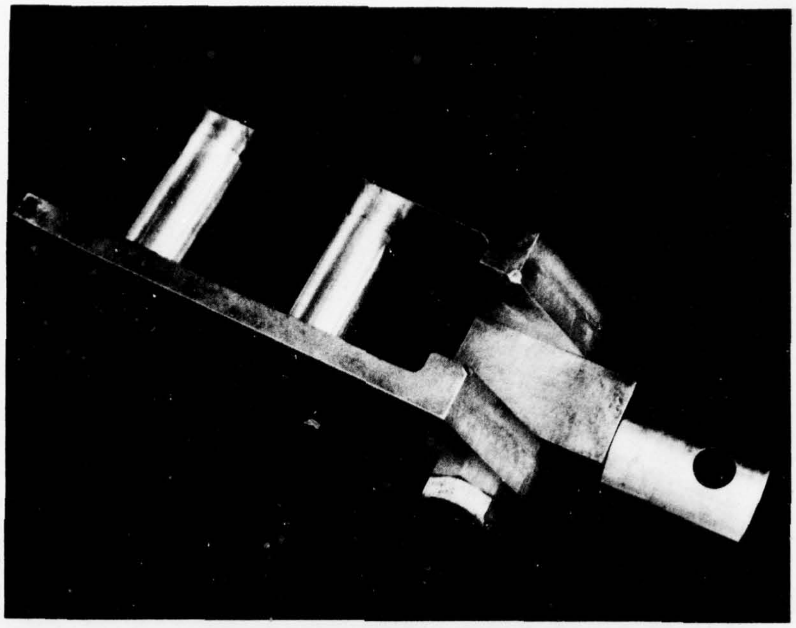


Figure 12a. Photograph of a Double-Pin Jaw

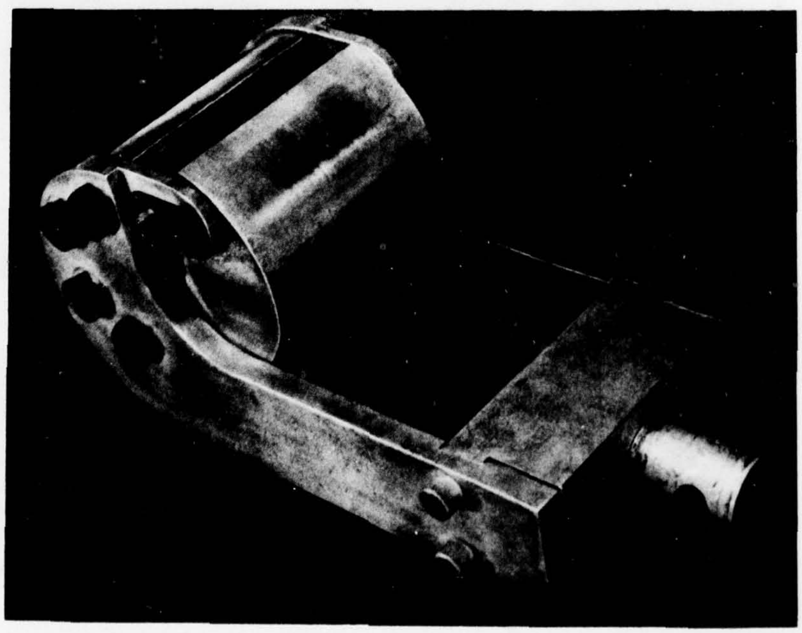


Figure 12b. Photograph of a Split Capstan Jaw

SECTION III

NARROW FABRIC PRODUCTION AND EVALUATION

Twenty-two narrow fabrics were designed and produced during the current program. One of the designs was supplied by Bally Ribbon Mills because it had a better strength/weight ratio than FRL's attempts to produce a high efficiency, lightweight ribbon. The FRL design has been included in the list of items produced however, since the lighter weight Bally ribbon eventually proved difficult from a seaming standpoint. Jointed specimens made from the Bally ribbon pulled apart during tensile testing at a very low force and were also judged poor due to the distortion resulting from low filling yarn count. Attempts to overcome this deficiency by applying a light resin coating to the ribbon were unsuccessful. This work is described in Appendix A.

The FRL-designed 400 lb ribbon performed well but its strength-to-weight index was extremely low, making it also a less than optimum product. Additional work is needed to arrive at a solution to this problem. After the proper design was achieved approximately twenty yards of each item was prepared for delivery to AFFDL. A summary of the constructional characteristics of final configurations of the various ribbons and webbings is shown in Table 5. Precise air permeability measurements were impossible on many of these items due to their relatively narrow widths. A smaller than normal air flow orifice had to be used on the Frazier Air Permeometer and this, combined with the extremely low permeability of the items being tested, provided very low scale readings which reduced the precision of measurement. However, most of the values are low enough so that the ribbons can be considered almost impermeable. The only exception to this is the 2 inch wide, 400 lb ribbon developed by Bally Ribbon Mills. At 80 cf/sq ft-min this ribbon is significantly different from all others developed. This high air permeability and the associated relatively high yarn mobility results in a degree of ribbon sleaziness which FRL had tried to avoid in their designs which, as a result, led to an undesirably high weight for this ribbon strength.

A summary of tensile properties of these same ribbons and webbings is shown in Table 6. In all but three items strength translational efficiencies in excess of 70% have been attained. No reason is readily apparent for the failure to develop higher strength efficiency for these materials, although

TABLE 5

CONSTRUCTION OF KEVLAR NARROW FABRICS

Width (inch)	Nominal Tensile Strength (lb)	Weight (oz/yd)	Thick ness (inch)	Weave	Air Permeability (ft^3/ft^2-min)	Warp den/ply/twist	Total Ends	Filling den/ply/twist	Picks per Inch	FRL Sample No. (3007-)
2	400	0.28	0.009	plain	40	200/1/2	72	1000/1/0	30	-183
	400	0.12	0.007	plain	80	200/1/2	60	200/1/0	50	-200[1]
	600	0.14	0.005	plain	30	200/1/2	92	200/1/0	46	-206
	800	0.16	0.006	plain	< 5	200/1/2	124	200/1/0	42	-207
	1000	0.17	0.007	plain	<13	200/1/2	152	200/1/0	40	-228
	1500	0.26	0.012	plain	< 5	400/1/2	108	400/1/0	31	-181
	2000	0.30	0.012	plain	< 5	400/1/2	142	400/1/0	30	-229
	2500	0.37	0.011	plain	< 5	1000/1/2	77	400/1/0	26	-202
	3000	0.43	0.016	plain	< 5	1000/1/2	96	400/1/0	24	-211
	4000	0.59	0.019	plain	< 5	1000/2/2	58	1000/1/0	19	-184
	5000	0.79	0.030	plain	< 5	1500/1/2	110	1500/1/0	13	-233
	6000	0.99	0.036	plain	< 5	1500/1/2	140	1500/1/0	13	-255
	8000	1.05	0.040	plain	< 5	1500/1/2	160	1500/1/0	12	-210
1-3/4	1000	0.17	0.010	plain	< 5	200/1/2	156	200/1/0	34	-201
	3000	0.49	0.022	plain	< 5	1000/1/2	96	1000/1/0	17	-250
1-1/2	500	0.12	0.006	plain	33	200/1/2	82	200/1/0	48	-205
	1100	0.17	0.011	plain	< 5	200/1/2	172	200/1/0	35	-198
	3000	0.47	0.025	plain	< 5	1000/1/2	96	1000/1/0	18	-213
1	350	0.07	0.005	plain	<40	200/1/2	50	200/1/0	45	-234
	750	0.11	0.009	plain	<40	200/1/2	108	200/1/0	35	-178
	1500	0.21	0.015	plain	<40	400/1/2	108	400/1/0	26	-179
	3000	0.42	0.033	plain	< 5	1000/2/2	48	1000/1/0	15	-185
1/2	800	0.11	0.016	3/1 twill center reversal	<40	200/1/2	122	200/1/0	35	-177

1. Bally Ribbon Mills Style 2207A.

TABLE 6

TENSILE PROPERTIES OF KEVLAR NARROW FABRICS

Width (inch)	Tensile Strength (lb) Target	Tensile Strength (lb) Actual	Translational Efficiency[2] (%)	Weight (oz/yd)	S/W Index[3]	Joint Strength (lb)	Joint Efficiency (%)	Sample No. (3007-)
2	400	530	76	0.28	1.9	370	70	-183
	400	470	81	0.12	3.9	---[4]	--	-200[1]
	600	740	83	0.14	5.3	440	59	-206
	800	980	81	0.16	6.1	850	87	-207
	1000	1080	73	0.17	6.4	900	83	-228
	1500	1680	71	0.26	6.5	1440	86	-181
	2000	2440	78	0.30	8.1	1940	79	-229
	2500	2930	75	0.37	7.9	2680	91	-202
	3000	3410	70	0.43	7.9	2980	87	-211
	4000	4740	87	0.59	8.0	3530	74	-184
	5000	6070	76	0.79	7.7	5310	87	-233
	6000	6610	65	0.99	6.7	5880	89	-255
	8000	8700	75	1.05	8.3	7200	83	-210
1-3/4	1000	1160	77	0.17	6.8	1010	87	-201
	3000	3300	68	0.49	6.7	3060	93	-250
1-1/2	500	640	80	0.12	5.3	530	83	-205
	1000	1350	81	0.17	7.9	1120	83	-198
	3000	3420	70	0.47	7.3	2990	87	-213
1	350	410	84	0.07	5.9	240	59	-234
	750	850	81	0.11	7.7	600	71	-178
	1500	1650	69	0.21	7.9	1320	80	-179
	3000	3370	75	0.42	8.0	3180	94	-185
1/2	800	880	74	0.11	8.0	---[5]	--[5]	-177

1. Bally Ribbon Mills Style 2207A.
2. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; and 93.9 lb for 1000/2/2.
3. Tensile Strength/Weight (thousands of pounds/oz/yd).
4. Joint pulled apart.
5. Not tested.

in general it appeared during the many trials conducted that nonuniform warp tension might be responsible. Attempts to eliminate this difficulty were never completely successful until finally somewhat less than optimum designs were accepted as a temporary solution. When additional time and funding permits, it is recommended that further attempts be made to improve upon the strength translation efficiencies of these three items. S/W Index, the ratio of tensile strength in thousands of pounds to weight in oz/yd, is above 6.0 for all but four of the structures, these being the lowest strength items on the list (350, 400, 500, and 600 lb target strengths).

Joint efficiencies for standard lap joints (see Figure 13) were generally found to be in excess of 80% although again the two lowest strength ribbons (350 lb and 600 lb) were significantly lower.

Actual thread size, stitch pattern, stitch frequency and length of overlap varied depending upon the item being tested. The following general sewing configurations were employed:

1. Ribbons and webbings up to 2000 lb rated strength
   Size E Kevlar thread
   Seven stitches per inch
   Four inch overlap splice.

2. Ribbons and webbings above 2000 lb rated strength
   Size FF Kevlar thread
   Ten to twelve stitches per inch
   Six inch overlap splice.

In addition for all 2 inch wide ribbons and webbings a 5-point "double W" stitch pattern was used. A 4-point "double N" pattern was used for the 1-1/2 to 1-3/4 inch wide materials and a 3-point "double V" pattern was used for all 1 inch wide items.

In addition to tensile and joint studies the Work Statement required that several other tests be performed on selected structures from the list of items developed. Four webbings were evaluated for the following characteristics:

1. Load-extension behavior

2. Energy to rupture

3. Flexural rigidity

4. Wet shrinkage.

The webbings chosen were 2 inches wide, 800, 2500, and 8000 lb tensile strength and 1 inch wide, 1500 lb tensile strength.

The load-extension diagrams for the four materials evaluated are shown in Figures 14 through 17.

Table 7 lists the rupture loads, extensions and energies of the four webbings along with the other mechanical properties measured.

Shrinkage was determined by measuring known dimensions on each sample when dry, i.e., at 70°F and 65%RH, and then remeasuring the same dimensions, while wet, after having soaked in water at 70°F for approximately 24 hours. There was essentially no change.

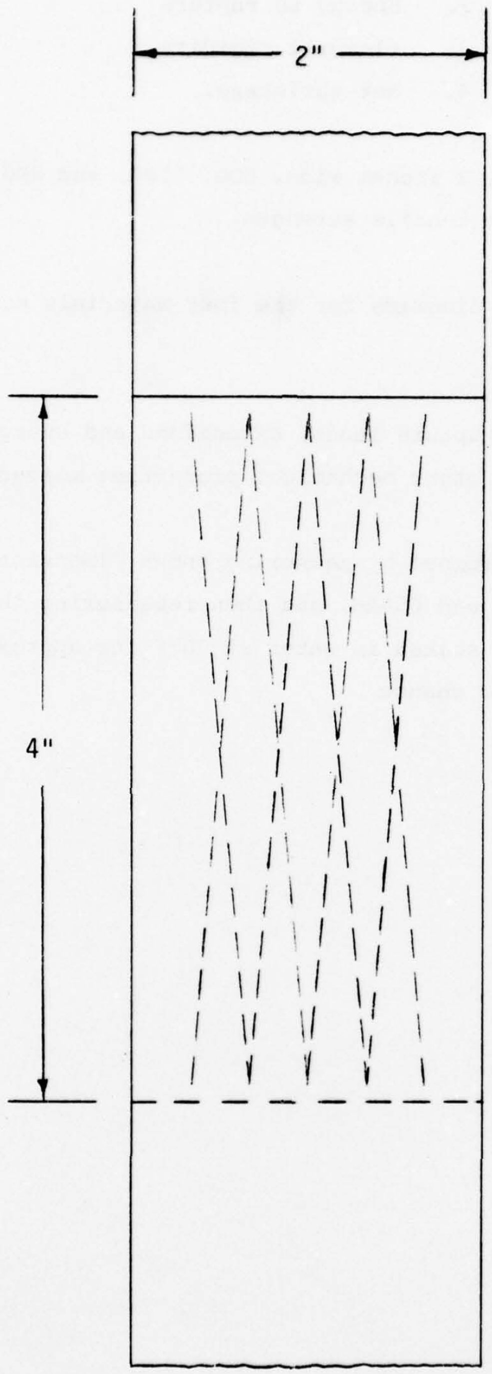


Figure 13. Standard Overlap Splice Configuration

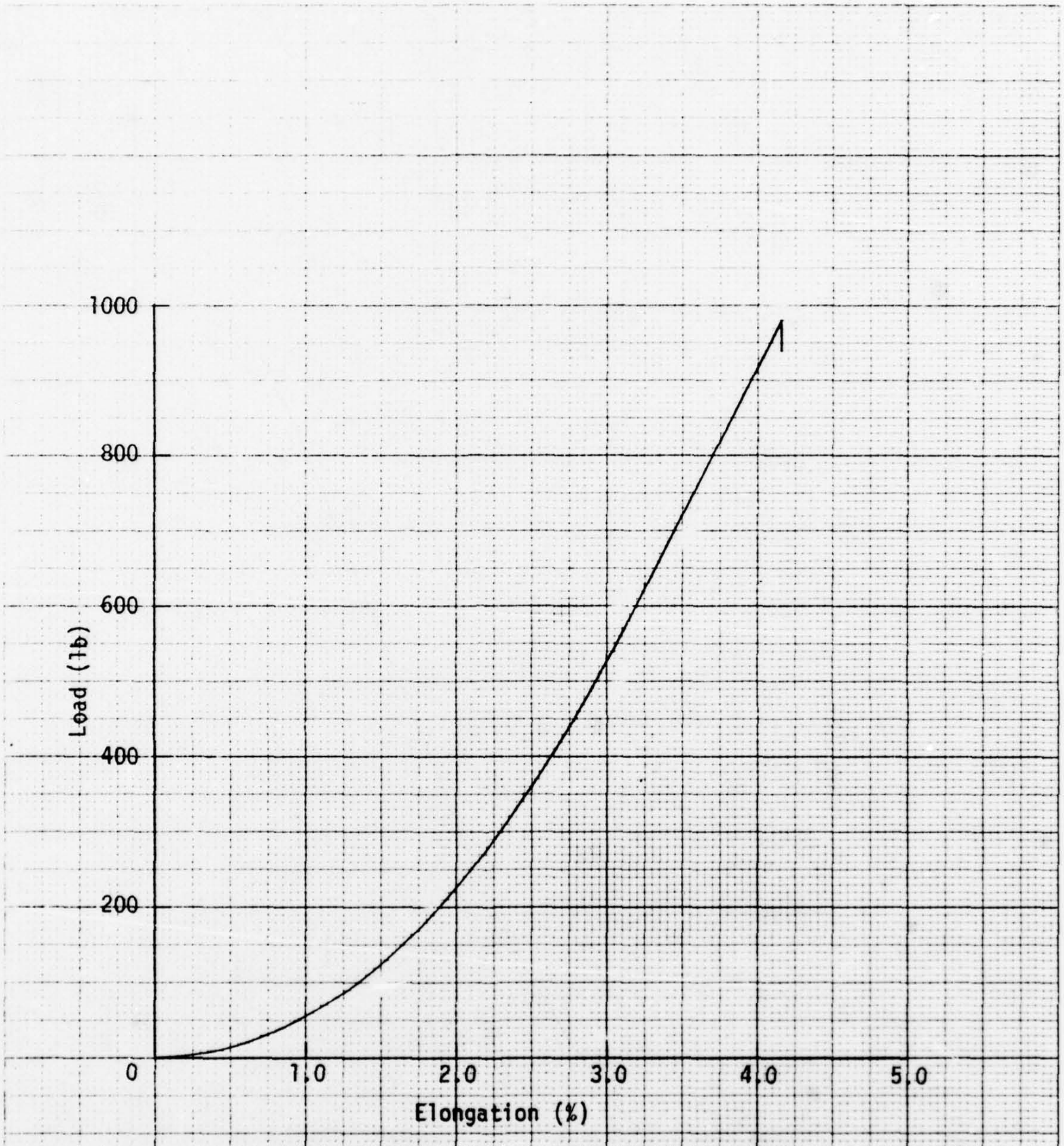


Figure 14. Average Quasi-Static Load Elongation Curve for 2" Wide, 800 Lb Kevlar 29 Ribbon (Average of 4 tests) (FRL Sample No. 3007-207)

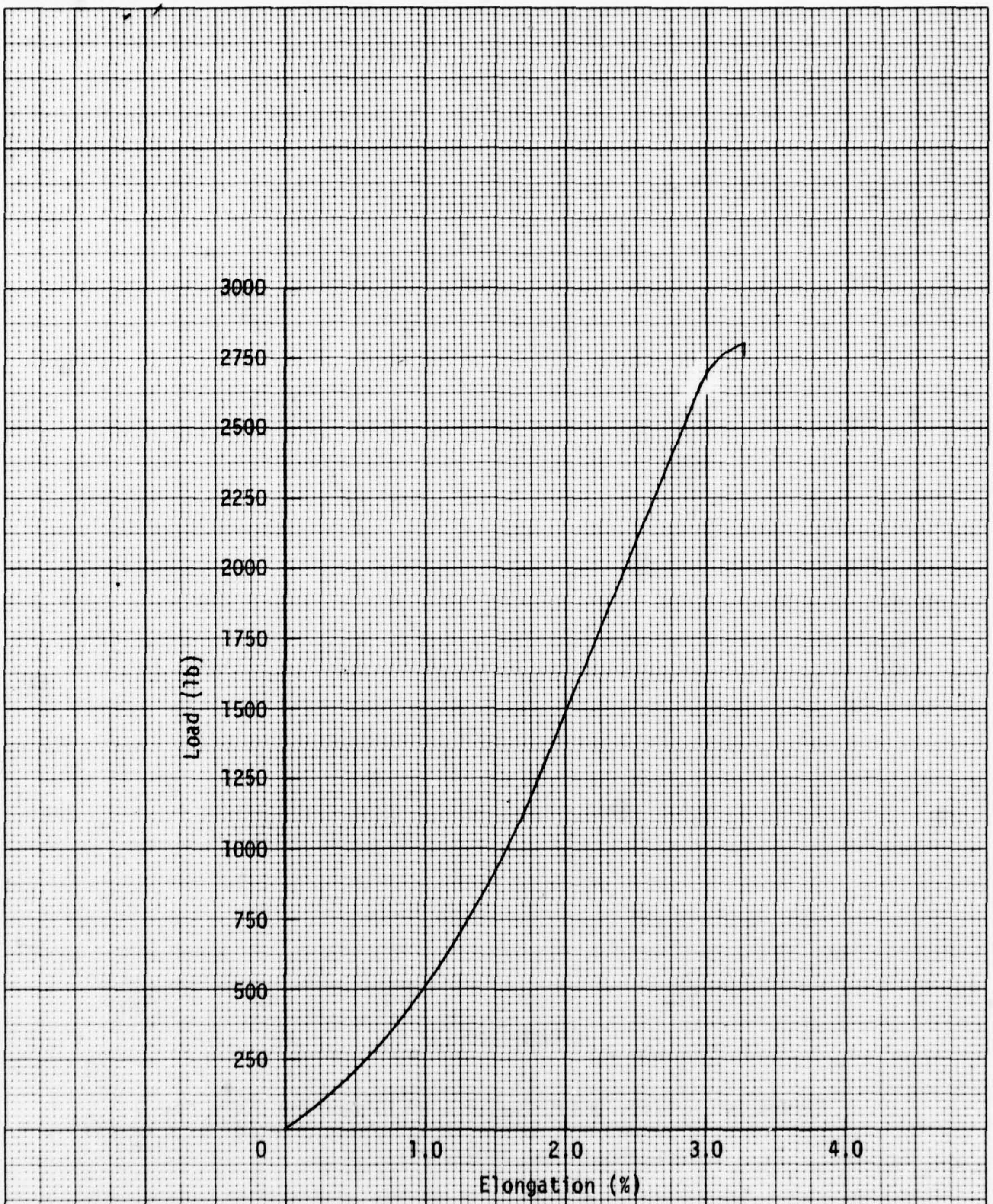


Figure 15. Average Quasi-Static Load Elongation Curve for 2" Wide, 2500 Lb Kevlar 29 Ribbon (FRL Sample No. 3007-202) (Average of 4 tests)

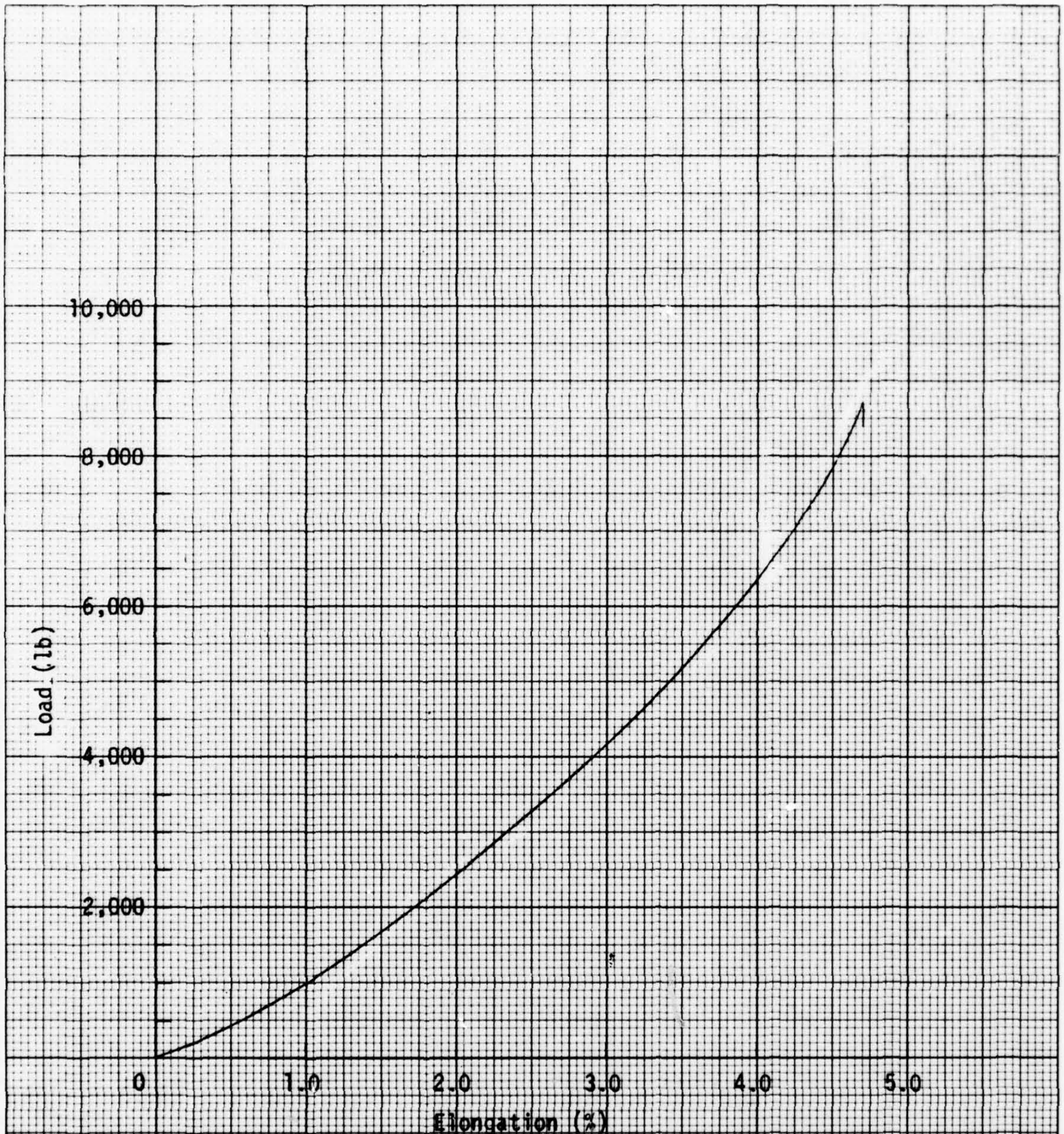


Figure 16. Average Quasi-Static Load Elongation Curve for 2" Wide, 8000 Lb Kevlar 29 Ribbon (Average of 4 tests) (FRL Sample No. 3007-210)

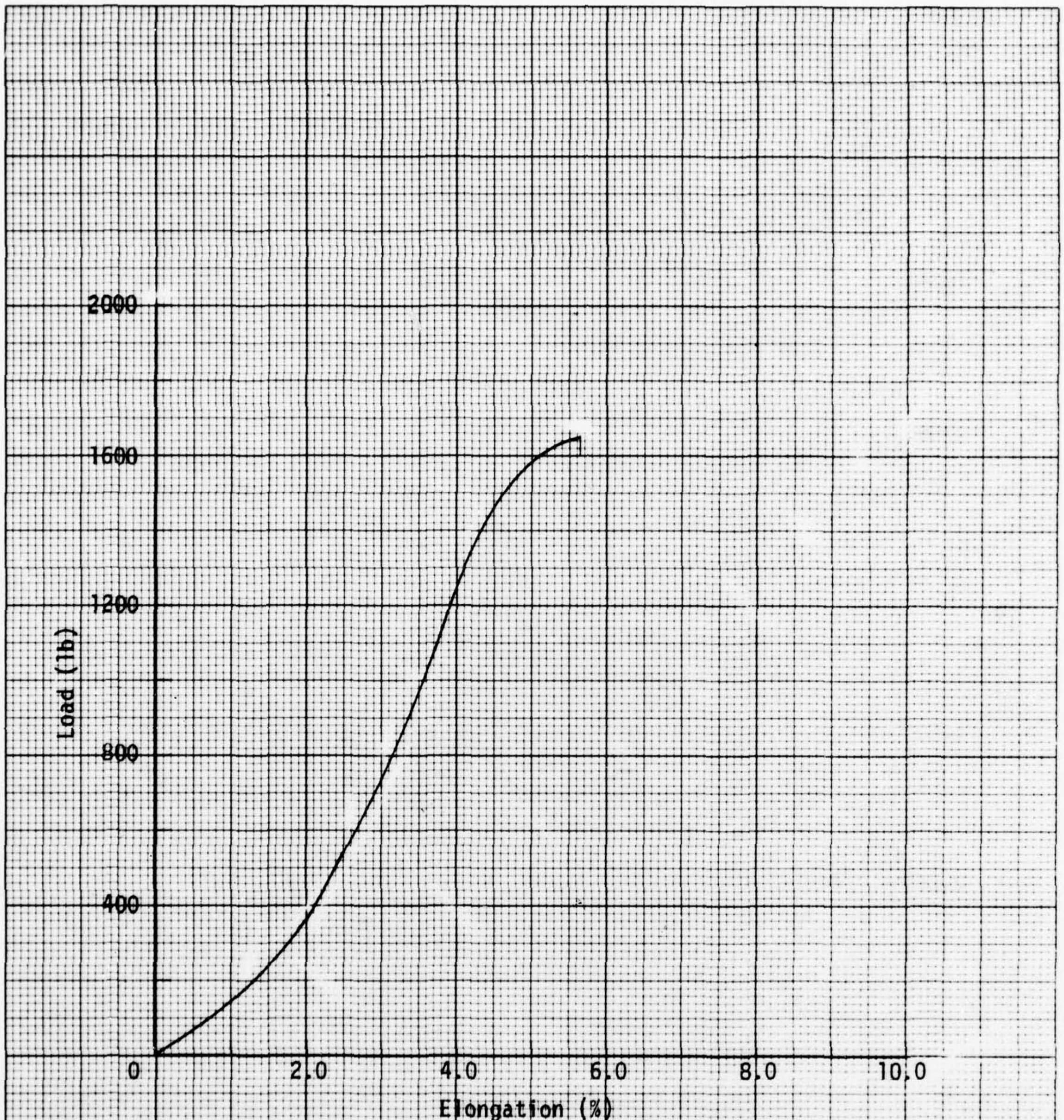


Figure 17. Average Quasi-Static Load Elongation Curve for 1" Wide, 1500 Lb Kevlar 29 Ribbon [Average of 4 tests] (FRL Sample No. 3007-179)

TABLE 7

MECHANICAL PROPERTIES OF SELECTED RIBBONS AND WEBBINGS

Width (inch)	Tensile Strength (%)		Rupture Extension (%)	Rupture Energy[1] (ft-lb/ft)	Flexural Rigidity[2] (g-cm^2/cm)	Wet Shrinkage (%) Length x Width	FRL Sample No. (3007-)
	Target	Actual					
2	800	980[3]	4.2	13	0.64	0.4 x 0.0	-207
2	2500	2800[4]	3.1	40	5.51	0.2 x 0.0	-202
2	8000	8700[5]	4.7	159	15.26	0.3 x 0.5	-210
1	1500	1650[4]	4.7	42	7.52	0.4 x 1.0	-179

1. Area under the load-elongation curve to rupture.
2. Cantilever test, ASTM Method D-1388.
3. Test Conditions: double pin jaws, 1" per minute crosshead speed, 10" gage length.
4. Test Conditions: double pin jaws, 1" per minute crosshead speed, 12" gage length.
5. Test Conditions: 4" capstan jaws, 1" per minute crosshead speed, 12" gage length.

SECTION IV

SEWING THREAD AND BRAID DESIGNS

Only one sewing thread was designed during the course of the program. A minimum strength of 115 lb was required in order to provide a thread between the 3-cord and 5-cord items developed during the previous contract. Two types of finish, a nylon and an acrylic, were applied experimentally to samples of this thread, and these were sent to AFFDL for sewing trials at ILC Steinthal, Inc. Both finishes proved satisfactory, and pending further information, no finish was applied to the bulk of the thread. Approximately 1/2 lb of finish-free thread was prepared for delivery to the Air Force. Its construction and tensile characteristics are shown in Table 8.

TABLE 8

CONSTRUCTION AND TENSILE CHARACTERISTICS OF KEVLAR 29 SEWING THREAD
(115 lb minimum breaking strength)

FRL Sample No.	Diameter (inch)	Tensile Strength (lb)	Weight (yd/lb)	Yarn Denier/Ply	Twist (tpi) Singles	Twist (tpi) Ply
3007 -196	0.032	122	1400	1000/3	7S	3.5Z

The Work Statement required that a design be developed for four braided cords: 100, 250, 2750 and 5000 lb minimum breaking strength. Within the framework of available yarn deniers and braiding equipment the number of designs possible to attain a given tensile strength is somewhat limited. In each design consideration was given to the tightness (pick spacing) of the braid with the final selection being made on the basis of a combination of high tensile efficiency and compactness of structure. The four items developed and the trial samples leading to the final selection of a production sample are shown in Table 9.

In conjunction with the development of the Kevlar braids several methods of splicing individual yarn ends during braid manufacture were evaluated to determine splice efficiency. The cord used for these experiments was made with 16 ends of 1500/2 yarn, braided at 7 picks per inch. Three types of yarn splice were used. One conformed to the requirements of the draft specification, and the other two were attempts at improvement over this technique. The specification requires that the end of the yarn being replaced be overlapped with the new end for a distance of 5 to 10 inches, the pair hand braided for

TABLE 9

KEVLAR BRAID CONSTRUCTIONS AND TENSILE PROPERTIES

Sample No.	No. of Carriers	Ends per Carrier	Basic Yarn Denier	Yarn Ply/Twist[1] (tpi)	Picks/ Inch	Actual Tensile Strength (lb)	Weight (oz/yd)	Strength Translational Efficiency (%)
A. 100 lb tensile strength								
3007-195-A	8	1	400	1/5	19	116	0.015	73
-B	8	1	400	1/5	15	131	0.013	82
-C*	8	1	400	1/5	12	140 (3 tests)	0.012	88
-D	8	1	400	1/5	10	141	0.012	88
B. 250 lb tensile strength								
3007-188-A	16	1	400	1/5	24	198	--	62
-B	16	1	400	1/5	12	283	--	82
-C	16	1	400	1/5	7	283	--	82
-D	16	1	400	1/5	16	270	--	84
-E*	16	1	400	1/5	14	301 (3 tests)	0.024	94
-F	16	1	400	1/5	12	315	--	98
-G	16	1	400	1/5	11	308	--	96
-H	16	1	400	1/5	21	288	--	90
C. 2750 lb tensile strength								
3007-194-A	16	1	1000	5/1	7	2725	--	68
-B	16	1	1000	5/1	7	2700	--	68
-C	16	1	1000	5/1	8	2575	--	64
-D	16	1	1000	5/1	6	2875	--	72
-E	16	1	1000	5/1	4	2950	--	74
3007-197-A*	16	1	1500	4/1	9	2900 (6 tests)	0.41	69
-B	16	1	1500	4/1	8	2870	--	64
-C	16	1	1500	4/1	7	3025	--	68
D. 5000 lb tensile strength								
3007-212-1	16	1	1500	7/1	3.5	5110	0.67	71
-2	16	1	1500	7/1	4.5	4700	0.69	65
-3	16	1	1500	7/1	5.5	4450	0.71	62
-4	16	1	1500	7/1	6.5	4350	0.76	60
-6	16	1	1500	7/1	8.0	3925	0.78	55
3007-215-A*	24	1	1500	5/1	5.5	5380 (3 tests)	0.74	68
-B	24	1	1500	5/1	8.0	4100	0.83	52
-C	24	1	1500	5/1	4.5	5650	0.73	72

*Chosen as production item.
--Not measured.
1. 1/2 carriers "S" direction, 1/2 carriers "Z" direction.

4 or 5 picks, and the tails run into the center of the braided cord. We used a spliced length of 6 inches and the end of the new yarn was run inside the braid for a distance of 1-1/2 inches instead of being cut flush. In a modification of this procedure, the spliced length was increased to 8 inches, and the new end was run inside the braid for 1-1/2 inches, then brought through to the outside, looped over one or two yarns, and reinserted into the inside of the braid in the opposite direction. Finally a splice was made using normal braiding practice of a 6 inch spliced length and cutting the ends flush with the surface of the braid.

Results of tensile tests on these samples are given in Table 10.

TABLE 10

TENSILE TESTS OF BRAIDS CONTAINING SPLICED ENDS

Control	Normal Practice	Mil Spec Standard Splice	Modification
1860	1717**	1680**	1660*
1820	1420*	1640*	1656*
	1715**	1810**	1680**
	1448**		1690*
mean 1840 lb	mean 1617 lb 88% efficiency	mean 1710 lb 93% efficiency	mean 1672 lb 91% efficiency

*Broke at splice.
**Broke on or at edge of capstan jaw.

The splicing procedure specified in the Military Specification is the best of the three procedures, but even it has a strength which is 7% less than the braid itself, probably because of the increased packing caused by the doubling of the ends, even for a short length. There was no evidence of yarn slippage at the splice.

SECTION V

BROAD FABRIC DESIGNS

In the design of the two broad fabrics, the main variable studied was air permeability which was required to fall between 50 and 90 cf/sq ft-min at 0.5 inch water pressure differential. In addition one of the fabrics was to exhibit a tensile strength of 300 lb/inch in both warp and filling directions while the second was to have a strength of 200 x 200 lb/inch. The designs developed with both of these fabrics use non-Rotoset yarn. The designation 200/0 signifies 200 denier yarn containing producer's twist, that is, as supplied by the manufacturer.

All of the experimental design changes which led to the final design are summarized in Table 11. It is interesting to note that the first construction for the 300 x 300 lb fabric had been made previously using zero twist Rotoset yarn, and gave a permeability of 67 cf/sq ft-min. The change to zero twist non-Rotoset yarn gave an unacceptably low permeability of only 9 cf/sq ft-min, due to the greater flattening of the yarns within the fabric structure. The construction finally arrived at (48 x 48, 200/ 5 tpi in the warp and 200/0 in the filling), utilized a twisted yarn in the warp in order (a) to make the yarn more compact and, thus, to increase the air permeability of the fabric, and (b) to make it easier to weave the fabric without damaging the warp yarns (though the warp yarns were further protected by addition of a polyvinyl alcohol size which was later removed by scouring). The proper permeability and strength was then achieved by using a zero-twist filling yarn.

The desired air permeability and strength was achieved in the second fabric by using zero-twist warp and filling yarns. This fabric represents the lightest fabric which could be made having reasonable structural integrity.

It is assumed that the small differences in warp and filling strengths which were measured, even though the ends per inch and picks per inch were the same, were the result of differences between warp and filling crimp levels. The sensitivity of Kevlar to the influence of yarn crimp on structure strength has been referred to previously. Thus, the relationship between warp and filling strengths may vary from one fabric to another, depending on specific weaving and finishing conditions. It is safe to assume, however, that they will both be above the specified minimum strength for the fabric.

Ten square yards of each of the constructions identified as having been adopted for the production sample were woven and delivered to AFFDL.

TABLE 11

DESIGN DATA FOR KEVLAR BROAD FABRICS

Ends x Picks per Inch	Weave Type	Denier/Twist (tpi) Warp	Denier/Twist (tpi) Filling	Air Permeability (ft^3/ft^2-min)	Tensile Strength (lb) W	Tensile Strength (lb) F	Fabric Weight (oz/sq yd)	Fabric Thickness (inch)
300 lb/inch x 300 lb/inch Tensile Strength								
54 x 54	plain	200/0	200/0	9	367	352	---	---
54 x 54	3/1 twill	200/0	200/0	87	---	---	---	---
52 x 52	plain	200/0	200/5	16	---	---	---	---
48 x 44	plain	200/5	200/0	121	368	308	---	---
45 x 44	plain	200/5	200/0	112	---	---	---	---
48 x 48	plain	200/5	200/0	72	357	---	---	---
48 x 48	plain	200/5	200/5	169	---	---	---	---
48 x 48	plain	200/5	200/0	69	366	430	---	---
48 x 48*	plain	200/5	200/0	89	383	408	2.7	0.006
200 lb/inch x 200 lb/inch Tensile Strength								
42 x 42	plain	200/0	200/0	50	---	---	---	---
40 x 40	plain	200/0	200/0	49	---	---	---	---
40 x 42	plain	200/0	200/0	47	---	---	---	---
40 x 44	plain	200/0	200/0	44	---	---	---	---
36 x 38	plain	200/0	200/0	53	---	---	---	---
36 x 36	plain	200/0	200/0	55	---	---	---	---
36 x 34	plain	200/0	200/0	69	---	---	---	---
36 x 34*	plain	200/0	200/0	87	255	242	1.8	0.004

--- not determined.
* final construction adopted for production sample.

SECTION VI

PREPARATION OF DRAFT MILITARY SPECIFICATIONS

Most of the designs for threads, cords, tapes and webbings which have been developed were incorporated into the Military Specifications referred to previously. These had been drafted originally in connection with contract no. F33615-73-C-5034. In these drafts, it was the general policy to use maximum weights which were approximately 10% higher, and minimum breaking strengths which were approximately 10% lower, than those actually measured. The drafts were reviewed, and some discrepancies and omissions noted in two letters sent to AFFDL. These comments are summarized below, and items noted which should be included as a result of later work.

1. MIL-W-87127 Webbing, Textile, Tubular, Para-Aramid, Intermediate Modulus

The maximum weights bore an inconsistent relationship to the actual weights. The following changes were suggested: Type I, 0.28, not 0.25; Type II, 0.25, not 0.30; Type III, 0.32, not 0.35; Type IV, 0.48, not 0.50; Type V, 0.68, not 0.70.

2. MIL-T-87128 Thread, Para-Aramid, Intermediate Modulus

The thread listed as Type A had been made from an experimental 100 denier Kevlar yarn which has not been made commercially available. The value of this design is questionable, therefore, and it was suggested that it be deleted from the specification. The "115-lb" thread should be included as follows:

Number Size	Yarn Denier	Ply	Twist (turns per inch) Singles	Twist (turns per inch) Ply	Length per Pound (min) Yards	Breaking Strength (lb min)
4	1000	3	7S	3.5Z	1300	110

3. MIL-C-87219 Cord, Coreless, Para-Aramid, Intermediate Modulus

(a) All lengths/lb listed were actual. It was suggested that the numbers be decreased by approximately 10% to read: I 13500, not 15000; II 6500, not 7200; III 3200, not 3600; IV 1100, not 1200; V 700, not 800;

VI 425, not 475; VII 335, not 375; VIII 200, not 225; IX 135, not 150; X 65, not 75; XI 60, not 65; XII 50, not 55.

(b) The actual strength of Type III was listed. It was suggested that 140 lb be changed to 125 lb minimum. Also the title of this column reads lb/min instead of lb min.

(c) Two cord constructions developed under this contract were not listed and should be included. They are:

Breaking Strength lb min	No. of Carriers	Ends per Carrier	Total Ends	Yarn Denier	No. Singles Yarns for Final Plied Yarn	Twist tpi	Picks per Inch	Length per lb ft min
250	16	1	16	400	1	5.0	14	2200
2600	16	1	16	1500	4	1.0	9	130

4. MIL-T-87130 Tape and Webbing, Textile, Para-Aramid, Intermediate Modulus

(a) Change maximum weights to bear a consistent relationship with actual weights as follows: Type I, Class 1, 0.06 not 0.05; Type IV, Class 1, 0.11 not 0.10; Type VI, Class 3, 0.12 not 0.11; Type VI, Class 5, 0.23 not 0.22; Type VI, Class 7, 0.52 not 0.44.

(b) Change minimum breaking strength of Type II, Class 1 to 700 lb from 500 lb. Add, if desired, a Type II, Class 2 construction as follows: 9/16 inch width; 0.08 oz/yd maximum weight; 500 lb minimum breaking strength; warp yarn 400 denier, 1 ply, 39 total ends, fill yarn 400 denier, 1 ply, 22 picks per inch; weave plain.

(c) In Type VI, Class 8 change total ends to 39 from 30.

(d) In Type VII, Class 1, the weave is plain.

(e) In Type I, Class 1, change picks per inch to 39 from 35.

(f) In Type XI, Class 5, change total ends to 92 from 96, and picks per inch from 50 to 46; in Type XI, Class 9b change picks per inch from 45 to 40.

(g) Because of the problem of yarn shifting in the Type XI, Class 3 construction, consider changing to the alternative construction given in Table 5 of this report, which has a maximum weight of 0.31 oz/yd, total warp ends of 72, fill yarn of 1000 denier, 1 ply, zero twist, 30 picks per inch.

(h) Add the following footnotes to Table I:

2/ 6 turns per inch in warp yarn (note typographical error in present footnote 2/)

3/ 5 turns per inch in warp yarn

4/ 4 turns per inch in warp yarn

5/ 3 turns per inch in warp yarn.

Add the following footnote references:

to footnote 2/ in I, 1; IV, 1; VI, 1.

to footnote 3/ in I, 2; II, 1; VI, 4; VII, 1; VIII, 1; X, 2.

to footnote 4/ in X, 3.

to footnote 5/ in X, 7.

Add "except as noted in Table I" to the first sentence in paragraph 3.2.1.2.

(i) Add the following constructions:

				Minimum	Warp			Filling			
Type	Class	Width (inches)	Maximum Weight (oz/yd)	Breaking Strength (lb)	Denier	Ply	Total Ends	Denier	Ply	Picks per Inch	Weave
VI	1	1	0.08	370	200	1	50	200	1	45	plain
X	4	1-3/4	0.54	3000	1000	1	96	1000	1	17	plain
XI	18	2	1.10	6000	1500	1	140	1500	1	13	plain

5. A draft specification for Cloth, Parachute, Cargo and Deceleration, Para-Aramid, Intermediate Modulus containing the descriptions of the two designs given in Section V of this report was written and submitted to AFFDL.

SECTION VII
CONCLUSIONS

Twenty-nine Kevlar 29 textile products have been designed as alternatives for nylon components in aerodynamic decelerators. In all but four of these, strength translational efficiencies in excess of 70% have been obtained.

Joint strength efficiencies of the narrow fabrics have been generally found to be 70-95% although two, low strength, light weight ribbons were 59% and one, the Bally Style 2207A, pulled apart at the joint rather than breaking. In an attempt to stabilize this ribbon, a study of the effectiveness of low add-on amounts of polymeric coating materials was made. The best of those coatings investigated was a nylon dispersion, Genton 110, which gave apparently good values of yarn pull-out force, did not increase the stiffness of the ribbon excessively, and resisted pressure packing conditions. This coating was applied to sufficient ribbon to permit further evaluation by AFFDL.

Fabric design, processing conditions and tensile test technique all require careful attention in order to maximize the tensile strength advantages offered by Kevlar 29 filament yarns. An attempt to develop a rational approach to the design of efficient Kevlar fabrics proved to be only of limited usefulness, and fabric design for Kevlar materials still remains a matter of trial and error guided by the elusive benefits of experience.

During the course of this work, it was found that optimum strength in woven Kevlar fabrics does not necessarily result when the load-bearing yarns contain the twist which gives optimum yarn strength. Work done at Sandia Laboratories, as well as at FRL, showed that it was usually better, and never worse, to use low twist yarns rather than optimum twist yarns in woven fabrics, presumably due to the beneficial effect of the lower warp crimp which results from the flattening of the low twist yarns. Thus, all of the constructions developed in the present work use yarns containing minimum usable twist.

One major problem which arose in the early development of constructions for 2" ribbons was the sensitivity which these structures exhibited to the

technique used in tensile testing. The use of capstan jaws invariably resulted in jaw breaks and indications of nonuniform stress application, which gives low estimates of breaking strength. A double-pin jaw design suggestedby AFFDL gave better breaks in these materials, and significantly higher values for breaking strength. These jaws were used throughout the present work for 2" wide materials as well as for cut strips of broad fabrics. This problem led to the establishment of another contract, F33615-78-C-3406, to develop optimum techniques for tensile testing Kevlar materials. This work is now underway at FRL.

As a result of drafts developed under this contract, four Military Specifications were issued covering sewing threads[3], cords[4], tubular webbings[2], tapes, ribbons and webbings[5] made from "para-aramid, intermediate modulus" fibers. These include most of the designs described herein, and recommendations have been made to add the remainder of the designs to these specifications. A Military Specification for cloth was drafted[6] and forwarded to AFFDL for their consideration.

VIII. REFERENCES

1. AFML-TR-74-65, Part IV. Design of Parachute Component Materials from Kevlar 29 and 49. July 1976.

2. MIL-W-87127 Webbing, Textile, Tubular, Para-Aramid, Intermediate Modulus, USAF. 17 May, 1978.

3. MIL-T-87128 Thread, Para-Aramid, Intermediate Modulus, USAF. 17 May, 1978.

4. MIL-C-87129 Cord, Coreless, Para-Aramid, Intermediate Modulus, USAF. 2 August, 1978.

5. MIL-T-87130 Tape and Webbing, Textile, Para-Aramid, Intermediate Modulus, USAF. 17 May, 1978.

6. Draft Tentative Military Specification for Cloth, Parachute, Cargo and Deceleration, Para-Aramid, Intermediate Modulus. 23 October, 1978.

APPENDIX A

RESIN COATING OF 2 INCH, 400 LB RIBBONS

In an attempt to improve joint efficiency and to minimize distortion resulting from aerodynamic stress, a study was made to find a polymeric coating which could be applied at low levels of add-on so as not to increase the weight excessively. It was also stipulated that the coated ribbon must be capable of surviving pressure packing without sticking, and must remain flexible enough to perform satisfactorily.

1. Kevlar Material

Candidate coatings were evaluated using the 2 inch, 400 lb Kevlar ribbon described in Table 5 as Bally Ribbon Style 2207A.

2. Evaluation

The effectiveness of the compounds which are tried was evaluated initially in three laboratory tests:

(a) Yarn pullout force

The intent of the application is to reduce the tendency for yarns to slide over one another in the structure. This is to be accomplished by sticking crossing yarns together, or increasing the coefficient of friction, or both. Thus, a primary test employed was to measure the force required to pull a single yarn out of the fabric. The procedure was as follows:

The filling yarns at one end of a 3 to 4 inch length of ribbon were ravelled out, leaving a fringe of protruding warp yarns about 1/2 inch long. All of this fringe was cut off except for one centrally located warp yarn. This yarn was then cut with a razor blade 2 inches back into the woven fabric. The woven fabric was held in one flat-face jaw of an Instron and the protruding end of yarn in the other. The crosshead was lowered at a speed of 2 inches per minute, and the force required to pull the yarn out of the fabric was recorded. The trace showed an initial high peak, followed by a continuously

decreasing force as the yarn was withdrawn. The height of the initial peak was read as the force required to initiate yarn slippage. This is called the "yarn withdrawal force."

(b) Stiffness

The degree of stiffening produced by these coatings was also measured using the cantilever test (ASTM D 1388). The results are given as the bending length in centimeters.

(c) Sticking

Because the parachutes made from treated ribbons may be pressure packed, it is important that any treatment used does not cause the ribbons to stick together. This was evaluated under simulated pressure packing conditions as follows.

Specimens 4 inches long were cut from the treated ribbons and folded in the middle. The folded specimens were then stacked, with an aluminum foil separator between successive specimens. The stack was placed between aluminum plates and loaded in the Instron to 1000 lb (250 psi). The plates were then clamped using two C-clamps and the assembly removed from the Instron and left in an oven at 100°C for 24 hours. After the stack was removed from the oven and allowed to cool to room temperature, the specimens were unfolded individually and the degree of sticking estimated.

3. Potential Coatings

Initial trials were run using the following compounds:

(a) Polyvinyl butyral - Butvar dispersion BR, Monsanto Chemical Corp.

(b) Polyurethane - Helastic WX2430 (fully reacted), Wilmington Chemical Corp.

(c) Epoxide resin - Eponite 812 Shell Chemical Corp.

(d) Syton - a colloidal silica.

Approximately one yard pieces of the ribbon were passed through a pan of the desired dilution of each reagent and then through squeeze rolls. This resulted in a wet pickup of about 50% on the air-dry weight of the fabric. The impregnated fabrics were then dried and cured in an oven at an appropriate temperature, as indicated below.

Concentrations and curing conditions used were:

(a) Polyvinyl butyral - Estimated dry pickup of approximately 1% and 1-1/2% (solution concentrations of 15% and 25%). Dried and cured for 10 minutes at 300°F.

(b) Polyurethane - Estimated dry pickup of approximately 1% and 2% (solution concentrations of 15% and 30% product). Dried and cured for 10 minutes at 300°F.

(c) Epoxide - Estimated dry pickup of approximately 1.5% and 4.5% (11.4 g or 34.2 g product with an equal weight of methanol, 1 g Triton X-100 and 1.4 g or 4.2 g zinc fluoroborate [40% solution] made up with water to 400 g total). Dried and cured for 5, 10 and 20 minutes at 400°F.

(d) Syton - Estimated dry pickup of approximately 2% (solution concentration of 10% of product). Dried for 15 minutes at 250°F.

The results of these measurements are shown in Table 12. Although the magnitude of pull-out force needed for satisfactory performance in service is not known, it is clear that the polyvinyl butyral and the epoxide were more effective than the polyurethane and the Syton.

TABLE 12

YARN WITHDRAWAL FORCE

Finish	% Dry Pickup	Drying and Curing Conditions	Yarn Withdrawal Force (grams and range of values)	Number of Tests
none	---	---	59 (49-67)	10
polyvinyl butyral	1	10 min 300°F	301 (160-400)	9
	1-1/2	10 min 300°F	895 (610-1000)	10
polyurethane	1	10 min 300°F	54 (40-68)	10
	2	10 min 300°F	84 (65-114)	6
epoxide	1-1/2	5 min 400°F	119 (118-120)	3
	1-1/2	10 min 400°F	229 (220-235)	3
	1-1/2	20 min 400°F	168 (135-185)	3
	4-1/2	5 min 400°F	139 (130-146)	3
	4-1/2	10 min 400°F	607 (475-820)	3
	4-1/2	20 min 400°F	1490 (1340-1600)	3
Syton	2	15 min 250°F	73 (69-77)	3

TABLE 13

FABRIC STIFFNESS

Treatment	% Dry Pickup	Bending Length (cm)	Number of Tests
none	--	4.4	4
polyvinyl butyral	1	5.3	4
	1-1/2	7.2	4
polyurethane	1	3.9	4
	2	4.5	4
epoxide	1-1/2	5.0	4
	4-1/2	5.9	4
Syton	2	3.8	4

Note: None of the fabrics was unacceptably stiff, although the polyvinyl butyral treatment gave the ribbon a rather papery hand.

The results of this evaluation were as follows:

(a) Polyvinyl butyral - All specimens were stiffened, due to sticking. Although they could be unfolded without damage to either surface, this coating would have to be rated unacceptable.

(b) Polyurethane - No sticking occurred, but an oily substance had exuded from the resin which left the surface wet and greasy.

(c) Epoxide - No sticking occurred at either level of add-on.

(d) Syton - No sticking occurred.

The results of these tests indicated clearly that the epoxide showed the best promise as a coating for parachute materials. No further studies involving the other coatings were made.

Additional work was then done to improve the method of applying Eponite 812. This product contained an oily component which had to be kept in suspension for at least 30 minutes, the duration of a typical plant run. A variety of mixtures was made up and applied to the ribbon, as it was not known whether the addition of components designed to keep the oily material in suspension would affect the bonding efficiency of the epoxide. The various trials which were made are summarized in Table 14.

Because of these encouraging results, it was decided to proceed with the application of the epoxide finish under plant conditions. Unfortunately, when Shell Chemical Company was contacted for an additional supply of Eponite 812, we were told that production of this material has just been discontinued because of a potential carcinogenic problem. Our experiments are only of academic interest at present, therefore, but if a similar material should become available again it should be considered as a potentially useful finish for Kevlar ribbons and webbings.

Search for an alternative to the epoxide led to trials with a nylon dispersion, Genton 110, from General Plastics Corporation, Bloomfield, N.J., as well as with polyvinyl alcohol, polyvinyl acetate, a mixture of polyvinyl

TABLE 14

APPLICATION OF EPON 812 TO KEVLAR RIBBON (2", 400 lb, Bally Ribbon Style 2207A)

Stock* Solution (g)	Epon Product (g)	PVA (g)	MeOH (g)	$Zn(BF_4)$ (g)	TRX-100 (g)	Water (g)	Cure Time (min)	Cure Temp (°F)	Pull-out Force (g)
2.5	30	---	30	7.5	5	425.0	5	400	98
2.5	15	---	15	3.8	5	458.7	5	400	31
---	7.5	5	12.5	1.9	5	468.1	5	400	53
---	30	5	35	7.5	5	417.5	5	400	69
---	30	5	35	7.5	5	417.5	5	450	78
---	30	10	40	7.5	5	407.5	5	400	79
---	30	10	40	7.5	5	407.5	5	450	72
---	30	6.2	36.2	7.5	5	415.0	5	400	125
---	30	6.2	36.2	7.5	5	415.0	10	400	127
---	30	7.5	37.5	7.5	5	412.5	5	400	123
---	30	7.5	37.5	7.5	5	412.5	5	450	139
---	30	5	35	7.5	5	417.5	5	400	154
							10	400	504
							20	400	506
---	30	---	30	7.5	5	427.5	5	400	427
							10	400	631
							20	400	1428

*10g Elvanol T-25 polyvinyl alcohol (PVA) + 10 g MeOH + 480 g water.

alcohol and polyvinyl butyral, and two materials submitted by Bally Ribbon Mills, Silicone DC75 and Celluset.

Using concentrations designed to give 1-2% solids pickup, these materials were applied in the laboratory to short lengths of the Kevlar ribbon so that sticking and yarn pull-out tests could be carried out. The results are given in Table 15.

TABLE 15

FINISH TRIALS ON KEVLAR RIBBON

Product	Sticking	Pull-out Force (g)
Polyvinyl alcohol + polyvinyl butyral	slight sticking	good
Polyvinyl alcohol alone	none	unacceptable
Polyvinyl acetate	excessive	---
Nylon dispersion (10% solids)		
100% concentration	none	---
50% dilution with water	none	233
Silicone DC75 (from Bally Ribbon)	none	78 (unacceptable)
Celluset (from Bally Ribbon)	excessive	---

These trials indicated the potential usefulness of Genton 110, the nylon dispersion. Accordingly, arrangements were made with Bally Ribbon Mills to apply this material, diluting the product 1:1 with water, to about 50 yards of ribbon. They also agreed to apply a nylon/alcohol solution, Gental, which they have used for some of their ribbons, to an additional 50 yards.

Yarn pull-out tests on the coated material gave values of 178 g for the Genton 110 treatment, and 100 g for the Gental treatment (value for untreated materials was 60 g). On the basis of our previous work, we felt that the Gental treatment was inadequate, possibly due to the concentration being too low. The Genton treatment, however, seemed satisfactory, and gave a pull-out force similar to that obtained in our lab trials (230 g).

Standard lap joints were sewn in the Genton-treated ribbon, and seam strength tests carried out wet at 70°F, 65%RH, and after wetting and air

drying back to 70°F, 65%RH. Sewing with this material was simple, and good stitching resulted. The jointed specimens failed, however at 170 lb for the dry specimens, 155 lb for the wet, and 148 lb after wetting and drying. These correspond to effective joint efficiencies of 36%, 33% and 31% respectively. Failure was not due to separation of the joint, but rather due to slippage of the filling yarns within and adjacent to the seamed area. It is apparent that the degree of bonding was inadequate for good joint strength, but may be sufficient to prevent slippage due to aerodynamic forces away from the seamed area. Approximately 35 yards of this material were sent to the Project Engineer for additional trials at ILC Steinthal, Inc.

Additional laboratory tests were then carried out to determine whether a higher add-on of Genton 110 could give a substantially higher pull-out force and better seam behavior. The ribbon was run through a dip tank containing full strength Genton 110 and then through squeeze rolls. Multiple passes were used to increase the solids add-on. Samples were removed after 1, 2, 3, 4, and 5 passes.

The yarn pull-out force for the sample which had been given a single pass was 850 grams, compared to 180 grams for the ribbon treated by Bally Ribbon Mills using a 50% dispersion. The value for the 5-pass sample was over 2,000 grams. The other samples were not tested.

Standard 5-point joints (see Figure 13) were sewn using 7 stitches per inch of E thread and a 4 inch overlap. In every case, failure was due to slippage of the filling yarns along the warp immediately outside the jointed area, just as it had been for the Bally treated ribbon. The loads at which this failure occurred were:

Treatment	Failure Load (lb)	Effective Joint Efficiency (%)
1 pass	177	38
2 passes	192	41
3 passes	171	36
4 passes	175	37
5 passes	faulty test	--

This is the same load as for the ribbon treated by Bally (170 lb). Obviously, this type of failure is not affected by any reasonable addition of

Genton 110, even though a significant amount of yarn-to-yarn adhesion has occurred. It is clear that the degree of adhesion which would be necessary to prevent slippage of this kind would require a heavy add-on, concentrated at the yarn cross-overs if possible, of a high strength (and, therefore, probably high modulus) adhesive. This would probably result in an unacceptable degree of stiffening of the ribbon, making it less acceptable in non-jointed areas.

The effect of Genton coating on migration of ribbon yarns in the ribbon free lengths of actual parachutes was investigated by subjecting all Kevlar 15.3 ft nominal diameter conical ribbon parachutes to flight conditions. Two tests were conducted by AFFDL to observe behavior of the 50 percent Genton concentration and one test was conducted using the 100 percent concentration. All horizontal ribbons were the same material used in the yarn pullout testing. Joints (horizontal ribbon splices) were fabricated by sewing the ends of the coated ribbon after dipping them in an anti-fraying compound marketed under the name "Sergene." The test items were restricted by two stages of reefing which held the skirt perimeter to 21.9 percent of the circumference of a 15.3 ft circle for five seconds after linestretch and to 35.2 percent for ten seconds after linestretch. The test items were deployed at a velocity of 630 feet per second (dynamic pressure of 400 pounds per square foot) and generated peak forces of 10,700, 12,500, and 10,000 pounds as the inflation stages were attained (values are representative of all three tests). Observation of onboard high speed photographic data and post test inspection of the test parachutes indicated that neither Genton coating concentration was effective in preventing unacceptable yarn migration in the ribbon free lengths.

This coating material does not seem to be an attractive solution to the problem.

Three possibilities suggest themselves:

1. It may be possible to design a joint which will better distribute the stress so as to minimize yarn slippage, but this seems unlikely. However, some 30 yards of the Bally-treated ribbon were sent to AFFDL for joining tests at ILC Steinthal, Inc. to see whether their seaming techniques alleviated the problem. A good joint was not developed from their work.

2. The joint itself, and the ribbon in the immediate neighborhood of the joint, may have to be coated with an adhesive material similar to that now being used by ILC Steinthal (Sergene, an anti-fray solution supplied by General Plastics, Bloomfield, N.J.).

3. Since this may be the only ribbon exhibiting this problem, a redesign of the ribbon itself, which no doubt would result in a somewhat heavier product, might eliminate the need for coating, or at least make a simple application acceptable.

APPENDIX B

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVLAR 29 NARROW FABRICS

Width (inch)	Tensile Strength (lb) Target	Actual	Denier/Ply/Twist Warp	Filling	Total Ends	Pick Wheel[2]	Strength[1] Translational Efficiency (%)	Weight (oz/ lin yd)
2	400	495	200/1/2	1000/1/0	80	34	64	--*
2	400	470	200/1/2	1000/1/0	80	34	61	--*
2	400	500	200/1/2	1000/1/0	80	34	64	--*
2	400	467	200/1/2	1000/1/0	80	34	60	--*
2	400	530	200/1/2	1000/1/0	80	34	68	--*
2	400	545	200/1/2	1000/1/0	80	34	70	--*
2	400	486	200/1/2	1000/1/0	80	30	63	--*
2	400	485	200/1/2	1000/1/0	80	30	63	--*
2	400	500**	200/1/2	1000/1/0	72	30	72	0.28
2	400	546**	200/1/2	1000/1/0	72	30	78	0.28
2	400	540**	200/1/2	1000/1/0	72	30	77	0.28
2	400	426	200/1/2	400/1/0	68	45	65	--*
2	400	444	200/1/2	400/1/0	68	45	67	--*
2	400	447	200/1/2	400/1/0	68	45	68	--*
2	400	405	200/1/2	400/1/0	68	45	61	--*
2	400	400	200/1/2	200/1/0	68	56	61	--*
2	400	380	200/1/2	200/1/0	68	60	58	--*
2	400	384	200/1/2	200/1/0	68	60	58	--*
2	400	402	200/1/2	200/1/0	68	38	61	--*
2	400	425	200/1/2	200/1/0	68	38	64	--*
2	400	357	200/1/2	200/1/0	68	50	54	--*
2	400	400	200/1/2	200/1/0	68	50	61	--*
2	600	680	200/1/5	200/1/0	92	48	76	--*
2	600	710	200/1/5	200/1/0	92	48	80	--*
2	600	690	200/1/2	200/1/0	92	48	77	0.14
2	600	600	200/1/2	200/1/0	92	48	67	0.14
2	600	625	200/1/2	200/1/0	92	48	70	0.14
2	600	650	200/1/2	200/1/0	92	48	73	0.14
2	600	650	200/1/2	200/1/0	92	48	73	0.14
2	600	735**	200/1/2	200/1/0	92	48	82	0.14
2	600	730**	200/1/2	200/1/0	92	48	82	0.14
2	600	743**	200/1/2	200/1/0	92	48	83	0.14
2	800	660	200/1/2	400/1/0	140	40	48	--*
2	800	675	200/1/2	400/1/0	140	40	49	--*
2	800	850	200/1/2	400/1/0	140	35	63	--*
2	800	820	200/1/2	400/1/0	140	35	60	--*
2	800	890	200/1/5	200/1/0	140	42	66	--*
2	800	985	200/1/5	200/1/0	140	42	72	--*
2	800	820	200/1/5	200/1/0	140	42	60	--*
2	800	895	200/1/5	200/1/0	140	42	66	--*
2	800	920	200/1/5	200/1/0	140	42	68	--*
2	800	760	200/1/3	200/1/0	119	46	66	--*

*Not determined.
**Tensile breaks on production item.
1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may vary slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Tensile Strength (lb) Actual	Denier/Ply/Twist Warp	Denier/Ply/Twist Filling	Total Ends	Pick Wheel[2]	Strength[1] Translational Efficiency (%)	Weight (oz/ lin yd)
2	800	830	200/1/3	200/1/0	119	46	72	--*
2	800	740	200/1/3	200/1/0	119	46	64	--*
2	800	730	200/1/3	200/1/0	119	46	63	--*
2	800	780	200/1/3	200/1/0	119	46	68	--*
2	800	765	200/1/3	200/1/0	119	46	66	--*
2	800	700	200/1/3	200/1/0	119	43	61	--*
2	800	780	200/1/3	200/1/0	119	42	68	--*
2	800	720	200/1/3	200/1/0	119	42	62	--*
2	800	705	200/1/3	200/1/0	119	54	61	--*
2	800	680	200/1/3	200/1/0	119	54	59	--*
2	800	720	200/1/3	200/1/0	119	54	62	--*
2	800	680	200/1/3	200/1/0	119	54	59	--*
2	800	720	200/1/3	200/1/0	119	54	62	--*
2	800	795	200/1/3	200/1/0	119	50	69	--*
2	800	765	200/1/3	200/1/0	119	50	66	--*
2	800	680	200/1/1	200/1/0	100	48	70	--*
2	800	640	200/1/1	200/1/0	100	48	66	--*
2	800	635	200/1/1	200/1/0	100	48	65	--*
2	800	677	200/1/1	200/1/0	100	47	70	--*
2	800	645	200/1/1	200/1/0	100	47	66	--*
2	800	645	200/1/1	200/1/0	100	47	66	--*
2	800	681	200/1/1	200/1/0	100	52	70	--*
2	800	708	200/1/2	200/1/0	100	52	73	--*
2	800	705	200/1/2	200/1/0	100	52	72	--*
2	800	803	400/1/2	400/1/0	62	54	59	--*
2	800	820	200/1/5	200/1/0	124	46	68	--*
2	800	780	200/1/5	200/1/0	124	46	65	--*
2	800	780	200/1/5	200/1/0	124	46	65	--*
2	800	875	200/1/5	200/1/0	124	44	73	--*
2	800	950	200/1/5	200/1/0	124	44	79	--*
2	800	870	200/1/5	200/1/0	124	44	72	--*
2	800	860	200/1/2	200/1/0	124	44	71	0.16
2	800	875	200/1/2	200/1/0	124	44	73	0.16
2	800	870	200/1/2	200/1/0	124	44	72	0.16
2	800	840	200/1/2	200/1/0	124	44	70	0.16
2	800	955**	200/1/2	200/1/0	124	44	79	0.16
2	800	980**	200/1/2	200/1/0	124	44	81	0.16
2	800	995**	200/1/2	200/1/0	124	44	83	0.16
2	800	970**	200/1/2	200/1/0	124	44	81	0.16
2	1000	998	200/1/6	200/1/0	172	44	60	--*
2	1000	1053	200/1/6	200/1/0	172	44	63	--*
2	1000	1210	200/1/6	200/1/0	172	42	73	--*
2	1000	1250	200/1/6	200/1/0	172	42	75	--*
2	1000	850	200/1/5	200/1/0	164	46	53	--*

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Actual	Denier/Ply/Twist Warp	Filling	Total Ends	Pick Wheel[2]	Strength[1] Translational Efficiency (%)	Weight (oz/ lin yd)
2	1000	835	200/1/5	200/1/0	164	46	52	--*
2	1000	890	200/1/5	200/1/0	164	46	56	--*
2	1000	1000	200/1/5	200/1/0	164	46	63	--*
2	1000	960	200/1/5	200/1/0	164	42	60	--*
2	1000	915	200/1/5	200/1/0	164	42	58	--*
2	1000	820	200/1/5	200/1/0	164	42	52	--*
2	1000	875	200/1/5	200/1/0	164	42	55	--*
2	1000	1125	200/1/5	200/1/0	164	46	71	--*
2	1000	1175	200/1/5	200/1/0	164	46	74	--*
2	1000	1015	200/1/5	200/1/0	164	46	64	--*
2	1000	880	200/1/5	200/1/0	164	46	55	--*
2	1000	890	200/1/6	200/1/0	120	42	76	--*
2	1000	850	200/1/6	200/1/0	120	42	73	--*
2	1000	890	200/1/6	200/1/0	120	42	76	--*
2	1000	850	200/1/6	200/1/0	120	42	73	--*
2	1000	840	200/1/6	200/1/0	120	42	72	--*
2	1000	1000	200/1/6	400/1/0	132	36	78	--*
2	1000	840	200/1/6	400/1/0	132	36	66	--*
2	1000	875	200/1/6	200/1/0	132	44	68	--*
2	1000	930	200/1/6	200/1/0	132	44	73	--*
2	1000	1045	200/1/2	200/1/0	152	42	71	0.17
2	1000	1140	200/1/2	200/1/0	152	42	77	0.17
2	1000	1158	200/1/2	200/1/0	152	42	78	0.17
2	1000	1030**	200/1/2	200/1/0	152	42	70	0.17
2	1000	970**	200/1/2	200/1/0	152	42	66	0.17
2	1000	1142**	200/1/2	200/1/0	152	42	77	0.17
2	1000	952	200/1/2	200/1/0	152	42	64	0.17
2	1000	900	200/1/2	200/1/0	152	42	61	0.17
2	1000	1158	200/1/2	200/1/0	152	42	79	0.17
2	1500	1125	400/1/2	1000/1/0	108	27	47	--
2	1500	1160	400/1/2	1000/1/0	108	27	49	--*
2	1500	1480	400/1/2	1000/1/0	108	24	62	--
2	1500	1390	400/1/2	1000/1/0	108	24	58	--*
2	1500	1150	400/1/2	1500/1/0	108	22	48	--*
2	1500	1155	400/1/2	1500/1/0	108	22	49	--*
2	1500	1080	400/1/2	1500/1/0	108	22	45	--*
2	1500	1070	400/1/2	1500/1/0	108	22	45	--*
2	1500	1255	400/1/2	400/1/0	108	40	53	--*
2	1500	1150	400/1/2	400/1/0	108	40	48	--*

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Actual	Denier/Ply/Twist Warp	Filling	Total Ends	Pick Wheel[2]	Strength[1] Translational Efficiency (%)	Weight (oz/ lin yd)
2	1500	1520	400/1/2	400/1/0	108	36	64	--*
2	1500	1330	400/1/2	400/1/0	108	36	56	--*
2	1500	1580	400/1/2	400/1/0	108	35	66	--*
2	1500	1480	400/1/2	400/1/0	108	35	62	--*
2	1500	1580	400/1/2	400/1/0	108	32	66	0.26
2	1500	1540	400/1/2	400/1/0	108	32	65	0.26
2	1500	1595	400/1/2	400/1/0	108	32	67	0.26
2	1500	1740	400/1/2	400/1/0	108	32	73	0.26
2	1500	1570	400/1/2	400/1/0	108	32	66	0.26
2	1500	1790	400/1/2	400/1/0	108	32	75	0.26
2	1500	1640**	400/1/2	400/1/0	108	32	69	0.26
2	1500	1638**	400/1/2	400/1/0	108	32	69	0.26
2	1500	1748**	400/1/2	400/1/0	108	32	74	0.26
2	2000	2220	400/1/4	400/1/0	172	24	59	--*
2	2000	2250	400/1/4	400/1/0	172	24	59	--*
2	2000	1800	400/1/5	400/1/0	140	30	58	--*
2	2000	1837	400/1/5	400/1/0	140	28	60	--*
2	2000	1897	400/1/5	400/1/0	140	28	62	--*
2	2000	1925	400/1/5	400/1/0	160	30	58	--*
2	2000	2582	400/1/5	400/1/0	160	30	78	--*
2	2000	1800	400/1/5	400/1/0	140	30	58	--*
2	2000	1837	400/1/5	400/1/0	140	28	60	--*
2	2000	1897	400/1/2	400/1/0	140	30	62	--*
2	2000	1925	400/1/5	400/1/0	160	30	58	--*
2	2000	2582	400/1/5	400/1/0	160	30	78	--*
2	2000	2220	400/1/5	400/1/0	142	30	71	0.30
2	2000	2225	400/1/5	400/1/0	142	30	71	0.30
2	2000	2200	400/1/2	400/1/0	142	30	70	0.30
2	2000	2000	400/1/2	400/1/0	142	30	64	0.30
2	2000	2430**	400/1/2	400/1/0	142	30	78	0.30
2	2000	2457**	400/1/2	400/1/0	142	30	79	0.30
2	2000	2430**	400/1/2	400/1/0	142	30	78	0.30
2	2500	2633	1000/1/4	1000/1/0	90	21	58	--*
2	2500	2538	1000/1/4	1000/1/0	86	21	58	--*
2	2500	2670	1000/1/4	400/1/0	82	26	64	--*
2	2500	2750	1000/1/4	400/1/0	82	26	66	--*
2	2500	3110	1000/1/2	400/1/0	82	26	74	--*
2	2500	3260	1000/1/2	400/1/0	82	26	78	--*
2	2500	3040	1000/1/2	400/1/0	82	26	73	--*
2	2500	2840**	1000/1/2	400/1/0	77	26	73	0.37
2	2500	2840**	1000/1/2	400/1/0	77	26	73	0.37
2	2500	3040**	1000/1/2	400/1/0	77	26	78	0.37
2	2500	3000**	1000/1/2	400/1/0	77	26	77	0.37

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Tensile Strength (lb) Actual	Denier/Ply/Twist Warp	Denier/Ply/Twist Filling	Total Ends	Pick Wheel[2]	Strength Translational Efficiency[1] (%)	Weight (oz/ lin yd)
2	3000	2940	1000/1/4	1000/1/0	110	22	53	--*
2	3000	3200	1000/1/4	1000/1/0	110	20	57	--*
2	3000	2303	1000/1/4	1000/1/0	100	24	45	--*
2	3000	2450	1000/1/4	1000/1/0	100	20	48	--*
2	3000	3220	1000/1/4	1000/1/0	100	17	64	--*
2	3000	3100	1000/1/4	1000/1/0	100	17	61	--*
2	3000	2425	1000/1/4	1000/1/0	86	24	56	--*
2	3000	2445	1000/1/4	1000/1/0	86	20	57	--*
2	3000	2200	1000/1/4	1500/1/0	92	24	47	--*
2	3000	2100	1000/1/4	1500/1/0	92	24	45	--*
2	3000	2620	1000/1/4	1500/1/0	92	20	56	--*
2	3000	2720	1000/1/4	1500/1/0	92	20	58	--*
2	3000	2620	1000/1/4	1500/1/0	92	20	56	--*
2	3000	2950	1000/1/4	1500/1/0	96	18	61	--*
2	3000	3240	1000/1/4	1500/1/0	96	18	67	--*
2	3000	2950	1000/1/4	1000/1/0	96	20	61	--*
2	3000	2870	1000/1/4	1000/1/0	96	20	59	--*
2	3000	3100	1000/1/4	1000/1/0	96	18	64	--*
2	3000	3150	1000/1/4	1000/1/0	96	18	65	--*
2	3000	3220	1000/1/4	1000/1/0	96	18	66	--*
2	3000	3000	1000/1/4	1000/1/0	96	18	62	--*
2	3000	3340	1000/1/4	1000/1/0	96	18	69	--*
2	3000	3450	1000/1/4	1000/1/0	96	18	71	--*
2	3000	3400	1000/1/4	1000/1/0	96	18	70	--*
2	3000	3050	1000/1/4	1000/1/0	96	17	63	--*
2	3000	2900	1000/1/4	1000/1/0	96	17	60	--*
2	3000	3140	1000/1/4	400/1/0	96	20	65	--*
2	3000	3340	1000/1/4	400/1/0	96	20	69	--*
2	3000	3430	1000/1/4	400/1/0	96	26	70	--*
2	3000	3650	1000/1/4	400/1/0	96	26	75	--*
2	3000	3420	1000/1/4	400/1/0	96	28	70	--*
2	3000	3300	1000/1/4	400/1/0	96	28	68	--*
2	3000	3450	1000/1/2	400/1/0	96	28	71	--*
2	3000	3100	1000/1/2	400/1/0	96	28	64	--*
2	3000	3150	1000/1/2	400/1/0	96	28	65	--*
2	3000	3150	1000/1/2	400/1/0	96	28	65	--*
2	3000	3100	1000/1/2	400/1/0	96	28	64	--*
2	3000	3300	1000/1/2	400/1/0	96	26	68	0.44
2	3000	3550	1000/1/2	400/1/0	96	26	73	0.44
2	3000	3050	1000/1/2	400/1/0	96	26	63	0.44
2	3000	3300**	1000/1/2	400/1/0	96	24	68	0.43
2	3000	3700**	1000/1/2	400/1/0	96	24	76	0.43
2	3000	3250**	1000/1/2	400/1/0	96	24	67	0.43

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF
EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Actual	Denier/Ply/Twist Warp	Filling	Total Ends	Pick Wheel[2]	Strength[1] Translational Efficiency (%)	Weight (oz/ lin yd)
2	4000	4380	1500/1/3	1500/1/0	96	16	63	--*
2	4000	4250	1500/1/3	1500/1/0	96	16	61	--*
2	4000	4250	1500/1/3	1500/1/0	96	16	61	--*
2	4000	4550	1500/1/3	1500/1/0	96	16	65	--*
2	4000	3860	1500/1/3	1500/1/0	90	18	59	--*
2	4000	3570	1500/1/3	1500/1/0	90	18	55	--*
2	4000	3600	1500/1/3	1500/1/0	90	18	55	--*
2	4000	3650	1500/1/3	1000/1/0	86	21	58	--*
2	4000	3390	1500/1/3	1500/1/0	92	20	51	--*
2	4000	4070	1500/1/3	1500/1/0	92	18	61	--*
2	4000	4000	1500/1/2	1500/1/0	92	18	60	--*
2	4000	3850	1500/1/2	1500/1/0	92	18	58	--*
2	4000	4280	1500/1/2	500/1/0	92	17	64	--*
2	4000	3750	1500/1/2	1500/1/0	92	17	56	--*
2	4000	3370	1500/1/2	1500/1/0	92	17	50	--*
2	4000	3550	1500/1/2	1500/1/0	92	17	53	--*
2	4000	3570	1500/1/2	1500/1/0	92	17	53	--*
2	4000	3640	1500/1/2	1500/1/0	92	17	54	--*
2	4000	3600	1500/1/2	1500/1/0	92	17	54	--*
2	4000	3020	1000/1/4	1000/1/0	114	20	52	--*
2	4000	3790	1000/1/4	1000/1/0	114	18	66	--*
2	4000	3790	1000/1/4	1000/1/0	114	16	71	--*
2	4000	3027	1000/1/4	1000/1/0	114	20	52	--*
2	4000	2815	1000/1/4	1000/1/0	114	19	49	--*
2	4000	2755	1000/1/4	1000/1/0	114	18	47	--*
2	4000	3390	1000/1/4	400/1/0	122	30	55	--*
2	4000	3370	1000/1/4	400/1/0	122	28	54	--*
2	4000	4200	1000/1/4	1000/1/0	122	16	68	--*
2	4000	3820	1000/1/4	1000/1/0	122	20	62	--*
2	4000	3930	1000/1/4	1500/1/0	124	16	63	--*
2	4000	4000	1000/1/4	1500/1/0	124	16	64	--*
2	4000	3950	1000/1/4	1500/1/0	124	16	63	--*
2	4000	3920	1000/1/4	1500/1/0	124	16	62	--*
2	4000	3930	1000/1/4	1500/1/0	129	16	60	--*
2	4000	4000	1000/1/4	1500/1/0	129	16	61	--*
2	4000	3950	1000/1/4	1500/1/0	129	16	60	--*
2	4000	3920	1000/1/4	1500/1/0	129	16	60	--*
2	4000	3730	1000/1/4	1500/1/0	129	16	57	--*
2	4000	3680	1000/1/4	1500/1/0	129	16	56	--*
2	4000	4840	1000/2/2	1000/1/0	58	20	89	0.59
2	4000	4720	1000/2/2	1000/1/0	58	20	87	0.59
2	4000	4755	1000/2/2	1000/1/0	58	20	87	0.59

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Tensile Strength (lb) Actual	Denier/Ply/Twist Warp	Denier/Ply/Twist Filling	Total Ends	Pick Wheel[2]	Strength Translational Efficiency[1] (%)	Weight (oz/lin yd)
2	4000	4515	1000/2/2	1000/1/0	58	20	83	0.59
2	4000	4450	1000/2/2	1000/1/0	58	20	82	0.59
2	4000	4580	1000/2/2	1000/1/0	58	20	84	0.59
2	4000	4620	1000/2/2	1000/1/0	58	20	85	0.59
2	4000	4220	1000/2/2	1000/1/0	58	20	77	0.59
2	4000	4605	1000/2/2	1000/1/0	58	20	85	0.59
2	4000	3860	1000/2/2	1000/1/0	58	20	71	0.59
2	4000	4360	1000/2/2	1000/1/0	58	20	80	0.59
2	4000	4500**	1000/2/2	1000/1/0	58	20	83	0.59
2	4000	4920**	1000/2/2	1000/1/0	58	20	90	0.59
2	4000	4800**	1000/2/2	1000/1/0	58	20	88	0.59
2	5000	4950	1000/1/4	1500/1/0	136	14	72	--*
2	5000	4630	1000/1/4	1500/1/0	136	14	67	--*
2	5000	4100	1000/1/4	1500/1/0	136	16	59	--*
2	5000	3565	1000/1/4	400/1/0	136	25	52	--*
2	5000	3735	1000/1/4	400/1/0	136	23	54	--*
2	5000	4063	1000/1/4	1000/1/0	136	18	59	--*
2	5000	4000	1000/1/4	1000/1/0	136	20	58	--*
2	5000	4420	1500/1/3	1000/1/0	110	21	55	--*
2	5000	4765	1500/1/3	1000/1/0	110	18	60	--*
2	5000	5090	1500/1/3	1000/1/0	110	17	64	--*
2	5000	5103	1500/1/3	1500/1/0	110	15	64	--*
2	5000	4550	1500/1/3	400/1/0	110	24	57	--*
2	5000	4700	1500/1/3	400/1/0	110	22	59	--*
2	5000	4700	1500/1/3	400/1/0	110	17	59	--*
2	5000	5370	1500/1/3	400/1/0	110	21	67	--*
2	5000	5200	1500/1/3	400/1/0	110	21	65	--*
2	5000	5230	1500/1/3	400/1/0	110	21	65	--*
2	5000	4500	1000/2/2	1000/1/0	74	18	64	0.72
2	5000	4250	1000/2/2	1000/1/0	74	18	61	0.72
2	5000	3350	1000/2/2	1000/1/0	74	17	48	0.71
2	5000	4400	1000/2/2	1000/1/0	74	17	63	0.71
2	5000	5000	1500/1/2	1000/1/0	110	18	63	--*
2	5000	3900	1500/1/2	1000/1/0	110	18	49	--*
2	5000	5450	1500/1/2	1500/1/0	110	14	68	0.91
2	5000	5160	1500/1/2	1500/1/0	110	14	65	0.91
2	5000	5520	1500/1/2	1500/1/0	110	14	69	0.91
2	5000	5730	1500/1/2	1500/1/0	110	13	72	0.77
2	5000	5550	1500/1/2	1500/1/0	110	13	69	0.77
2	5000	6180**	1500/1/2	1500/1/0	110	13	77	0.79
2	5000	6000**	1500/1/2	1500/1/0	110	13	75	0.79
2	5000	6020**	1500/1/2	1500/1/0	110	13	75	0.79

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF
EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Tensile Strength (lb) Actual	Denier/Ply/Twist Warp	Denier/Ply/Twist Filling	Total Ends	Pick Wheel[2]	Strength Translational Efficiency[1] (%)	Weight (oz/ lin yd)
2	6000	3850	1500/3/2	1500/1/0	50	15	--*	--*
2	6000	5300	1500/3/2	1500/1/0	50	12	--*	--*
2	6000	6400	1500/3/2	1500/1/0	50	12	--*	--*
2	6000	4950	1000/2/2	1000/1/0	99	13	--*	--*
2	6000	5700	1000/2/2	1000/1/0	99	13	--*	--*
2	6000	3650	1500/2/2	1500/1/0	60	13	--*	--*
2	6000	5400	1500/2/2	1500/1/0	60	13	--*	--*
2	6000	3500	1500/2/2	1500/1/0	58	13	--*	--*
2	6000	5200	1500/2/2	1500/1/0	58	13	--*	--*
2	6000	4100	1500/1/2	1500/1/0	120	12	47	0.83
2	6000	4800	1500/1/2	1500/1/0	120	12	56	0.83
2	6000	5300	1500/1/2	1500/1/0	120	13	61	--*
2	6000	5300	1500/1/2	1500/1/0	120	13	61	--*
2	6000	6500	1500/1/2	1500/1/0	120	12	75	0.83
2	6000	6000	1500/1/2	1500/1/0	120	12	69	0.83
2	6000	6300	1500/1/2	1500/1/0	120	11	73	0.81
2	6000	6600	1500/1/2	1500/1/0	120	11	76	0.81
2	6000	5180	1500/1/2	1500/1/0	120	13	60	0.84
2	6000	5280	1500/1/2	1500/1/0	120	13	61	0.84
2	6000	5580	1500/1/2	1500/1/0	120	12	65	--*
2	6000	5350	1500/1/2	1500/1/0	120	12	62	--*
2	6000	5580	1500/1/2	1500/1/0	120	13	65	--*
2	6000	5050	1500/1/2	1500/1/0	120	13	58	--*
2	6000	5650	1500/1/2	1500/1/0	120	12	65	--*
2	6000	5650	1500/1/2	1500/1/0	120	12	65	--*
2	6000	6500	1500/1/2	1500/1/0	120	12	74	0.83
2	6000	6600	1500/1/2	1500/1/0	120	12	76	0.83
2	6000	6200	1500/1/2	1500/1/0	120	13	72	0.85
2	6000	6300	1500/1/2	1500/1/0	120	13	73	0.85
2	6000	5575	1500/1/3	1500/1/0	120	13	63	0.84
2	6000	5500	1500/1/3	1500/1/0	120	13	62	0.84
2	6000	5500	1500/1/3	1500/1/0	120	13	62	0.84
2	6000	7100**	1500/1/2	1500/1/0	140	13	70	0.99
2	6000	5900**	1500/1/2	1500/1/0	140	13	58	0.99
2	6000	6550**	1500/1/2	1500/1/0	140	13	65	0.99
2	6000	6900**	1500/1/2	1500/1/0	140	13	68	0.99
2	8000	5900	1500/1/3	1500/1/0	160	14	50	1.06
2	8000	6150	1500/1/3	1500/1/0	160	14	52	1.06
2	8000	8050	1500/1/3	1500/1/0	160	12	68	1.05
2	8000	7400	1500/1/3	1500/1/0	160	12	62	1.05
2	8000	7050	1500/1/3	1500/1/0	160	13	60	1.05
2	8000	7400	1500/1/3	1500/1/0	160	13	62	1.05
2	8000	6300	1500/1/3	1500/1/0	160	13	53	1.05
2	8000	8200	1500/1/2	1500/1/0	160	13	70	1.05
2	8000	8100	1500/1/2	1500/1/0	160	13	69	1.05
2	8000	8900**	1500/1/2	1500/1/0	160	12	76	1.05
2	8000	8600**	1500/1/2	1500/1/0	160	12	74	1.05
2	8000	8700**	1500/1/2	1500/1/0	160	12	75	1.05
2	8000	8600**	1500/1/2	1500/1/0	160	12	74	1.05

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Actual	Denier/Ply/Twist Warp	Filling	Total Ends	Pick Wheel[2]	Strength[1] Translational Efficiency (%)	Weight (oz/ lin yd)
1-3/4	1000	1340	400/1/5	400/1/0	104	35	58	--*
1-3/4	1000	1280	400/1/5	400/1/0	104	35	56	--*
1-3/4	1000	1470	400/1/5	400/1/0	104	30	64	--*
1-3/4	1000	1460	400/1/5	400/1/0	104	30	64	--*
1-3/4	1000	700	200/1/2	200/1/0	156	46	47	--*
1-3/4	1000	780	200/1/2	200/1/0	156	46	53	--*
1-3/4	1000	775	200/1/2	200/1/0	156	46	52	--*
1-3/4	1000	910	200/1/2	200/1/0	156	42	61	--*
1-3/4	1000	795	200/1/2	200/1/0	156	42	54	--*
1-3/4	1000	920	200/1/2	200/1/0	156	42	62	--*
1-3/4	1000	1020	200/1/2	200/1/0	156	40	69	--*
1-3/4	1000	1160	200/1/2	400/1/0	156	29	78	--*
1-3/4	1000	1175	200/1/2	400/1/0	156	29	79	--*
1-3/4	1000	1080	200/1/2	400/1/0	156	29	73	--*
1-3/4	1000	1179	200/1/2	400/1/0	156	29	80	--*
1-3/4	1000	1105	200/1/2	200/1/0	156	40	73	--*
1-3/4	1000	1090	200/1/2	200/1/0	156	40	72	--*
1-3/4	1000	1120	200/1/2	200/1/0	156	40	74	--*
1-3/4	1000	1175	200/1/2	200/1/0	156	36	78	--*
1-3/4	1000	1180	200/1/2	200/1/0	156	36	78	--*
1-3/4	1000	1190**	200/1/2	200/1/0	156	34	79	0.17
1-3/4	1000	1050**	200/1/2	200/1/0	156	34	69	0.17
1-3/4	1000	1235**	200/1/2	200/1/0	156	34	82	0.17
1-3/4	1000	1260	200/1/2	200/1/0	156	32	83	--*
1-3/4	1000	1280	200/1/2	200/1/0	156	32	85	--*
1-3/4	1000	1335	200/1/2	200/1/0	156	30	88	--*
1-3/4	1000	1250	200/1/2	200/1/0	156	30	83	--*
1-3/4	3000	2900	1000/1/4	400/1/0	96	24	59	--*
1-3/4	3000	3150	1000/1/4	400/1/0	96	24	65	--*
1-3/4	3000	3170	1000/1/4	400/1/0	96	22	65	--*
1-3/4	3000	3370	1000/1/4	400/1/0	96	22	69	--*
1-3/4	3000	3130	1000/1/4	400/1/0	96	22	64	--*
1-3/4	3000	2950	1000/1/4	400/1/0	96	22	61	--*
1-3/4	3000	2730	1000/1/4	400/1/0	96	22	56	--*
1-3/4	3000	2700	1000/1/2	1000/1/0	96	19	56	0.50
1-3/4	3000	3300	1000/1/2	1000/1/0	96	19	67	0.50
1-3/4	3000	2950	1000/1/2	1000/1/0	96	20	61	0.52
1-3/4	3000	2950	1000/1/2	1000/1/0	96	19	61	0.50
1-3/4	3000	3100	1000/1/2	1000/1/0	96	17	64	0.47
1-3/4	3000	3375	1000/1/2	1000/1/0	96	17	70	0.47
1-3/4	3000	3275	1000/1/2	1000/1/0	96	16	68	0.47
1-3/4	3000	3100	1000/1/2	1000/1/0	96	16	65	0.47
1-3/4	3000	3000	1000/1/2	1000/1/0	96	20	62	0.52
1-3/4	3000	2700	1000/1/2	1000/1/0	96	20	56	0.52
1-3/4	3000	2950	1000/1/2	1000/1/0	96	20	61	0.52
1-3/4	3000	2600	1000/1/2	1000/1/0	96	20	54	0.52
1-3/4	3000	2850	1000/1/2	1000/1/0	96	20	59	0.52
1-3/4	3000	3200**	1000/1/2	1000/1/0	96	17	67	0.49
1-3/4	3000	3350**	1000/1/2	1000/1/0	96	17	70	0.49
1-3/4	3000	3350**	1000/1/2	1000/1/0	96	17	70	0.49

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF
EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Tensile Strength (lb) Actual	Denier/Ply/Twist Warp	Denier/Ply/Twist Filling	Total Ends	Pick Wheel[2]	Strength[1] Translational Efficiency (%)	Weight (oz/ lin yd)
1-1/2	500	560	200/1/5	200/1/0	82	50	71	--*
1-1/2	500	580	200/1/5	200/1/0	82	50	74	--*
1-1/2	500	530	200/1/2	200/1/0	82	50	67	0.12
1-1/2	500	580	200/1/2	200/1/0	82	50	74	0.12
1-1/2	500	540	200/1/2	200/1/0	82	50	68	0.12
1-1/2	500	622**	200/1/2	200/1/0	82	50	78	0.12
1-1/2	500	637**	200/1/2	200/1/0	82	50	80	0.12
1-1/2	500	660**	200/1/2	200/1/0	82	50	83	0.12
1-1/2	1100	1390	400/1/5	1000/1/0	104	22	61	--*
1-1/2	1100	1278	400/1/5	1000/1/0	104	22	56	--*
1-1/2	1100	1450	400/1/5	1000/1/0	104	22	63	--*
1-1/2	1100	1330	400/1/5	1000/1/0	104	22	58	--*
1-1/2	1100	1295	400/1/5	1000/1/0	104	24	57	--*
1-1/2	1100	1260	400/1/5	1000/1/0	104	24	55	--*
1-1/2	1100	1575	400/1/5	400/1/0	104	25	69	--*
1-1/2	1100	1570	400/1/5	400/1/0	104	25	69	--*
1-1/2	1100	1550	400/1/5	400/1/0	104	30	68	--*
1-1/2	1100	1480	400/1/5	400/1/0	104	30	65	--*
1-1/2	1100	1345	400/1/5	400/1/0	90	30	68	--*
1-1/2	1100	1495	400/1/5	400/1/0	90	30	77	--*
1-1/2	1100	1000	400/1/5	400/1/0	84	35	54	--*
1-1/2	1100	1055	400/1/5	400/1/0	84	35	57	--*
1-1/2	1100	1080	400/1/5	400/1/0	84	32	58	--*
1-1/2	1100	1060	400/1/5	400/1/0	84	32	57	--*
1-1/2	1100	1100	400/1/5	400/1/0	88	32	57	--*
1-1/2	1100	1110	400/1/5	400/1/0	88	32	57	--*
1-1/2	1100	1180	400/1/5	400/1/0	88	30	61	--*
1-1/2	1100	1095	400/1/5	400/1/0	88	30	57	--*
1-1/2	1100	1350	200/1/6	400/1/0	172	30	81	--*
1-1/2	1100	1330	200/1/6	400/1/0	172	30	81	--*
1-1/2	1100	1320	200/1/6	400/1/0	172	30	81	--*
1-1/2	1100	1340	200/1/6	400/1/0	172	30	81	--*
1-1/2	1100	1330	200/1/6	400/1/0	172	30	81	--*
1-1/2	1100	1200	200/1/6	200/1/0	172	36	73	--*
1-1/2	1100	1150	200/1/6	200/1/0	172	36	70	--*
1-1/2	1100	1140	200/1/6	200/1/0	172	35	70	--*
1-1/2	1100	1110	200/1/6	200/1/0	172	35	68	--*
1-1/2	1100	1130	200/1/6	200/1/0	172	30	69	--*
1-1/2	1100	1300	200/1/2	200/1/0	172	36	78	0.17
1-1/2	1100	1280	200/1/2	200/1/0	172	36	77	0.17
1-1/2	1100	1280	200/1/2	200/1/0	172	36	77	0.17
1-1/2	1100	1330**	200/1/2	200/1/0	172	36	80	0.17
1-1/2	1100	1370**	200/1/2	200/1/0	172	36	82	0.17
1-1/2	1100	1360	200/1/2	200/1/0	172	36	82	0.17

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVALR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Tensile Strength (lb) Actual	Denier/Ply/Twist Warp	Denier/Ply/Twist Filling	Total Ends	Pick Wheel[2]	Strength[1] Translational Efficiency (%)	Weight (oz/ lin yd)
1-1/2	3000	3065	1000/1/4	1000/1/0	96	20	67	--*
1-1/2	3000	3050	1000/1/4	1000/1/0	96	20	63	--*
1-1/2	3000	3160	1000/1/4	1000/1/0	96	20	65	--*
1-1/2	3000	3215	1000/1/4	1500/1/0	96	17	66	--*
1-1/2	3000	3060	1000/1/4	1500/1/0	96	17	63	--*
1-1/2	3000	3150	1000/1/4	1000/1/0	96	19	65	--*
1-1/2	3000	3300	1000/1/4	1000/1/0	96	19	68	--*
1-1/2	3000	3300	1000/1/4	1000/1/0	96	19	68	--*
1-1/2	3000	3030	1000/1/4	1000/1/0	96	19	62	--*
1-1/2	3000	3200	1000/1/4	1000/1/0	96	19	66	--*
1-1/2	3000	3070	1000/1/4	1000/1/0	96	19	63	--*
1-1/2	3000	3140	1000/1/4	1000/1/0	96	19	65	--*
1-1/2	3000	2930	1000/1/4	1000/1/0	96	19	60	--*
1-1/2	3000	3050	1000/1/4	1000/1/0	96	19	63	--*
1-1/2	3000	3175	1000/1/4	1000/1/0	96	19	65	--*
1-1/2	3000	3320	1000/1/4	1000/1/0	96	18	68	--*
1-1/2	3000	3200	1000/1/4	1000/1/0	96	18	66	--*
1-1/2	3000	3210	1000/1/4	1000/1/0	96	18	66	--*
1-1/2	3000	3050	1000/1/4	1000/1/0	96	18	63	--*
1-1/2	3000	3125	1000/1/4	1000/1/0	96	18	64	--*
1-1/2	3000	3190	1000/1/4	1000/1/0	96	18	66	--*
1-1/2	3000	3290	1000/1/4	400/2/0	96	19	67	--*
1-1/2	3000	3300	1000/1/4	400/2/0	96	19	68	--*
1-1/2	3000	3490	1000/1/4	400/2/0	96	18	72	--*
1-1/2	3000	2975	1000/1/4	400/1/0	96	16	61	--*
1-1/2	3000	3025	1000/1/4	400/1/0	96	18	62	--*
1-1/2	3000	3015	1000/1/4	400/1/0	96	18	62	--*
1-1/2	3000	3300	1000/1/2	1000/1/0	96	19	68	0.47
1-1/2	3000	3300	1000/1/2	1000/1/0	96	19	68	0.47
1-1/2	3000	3300	1000/1/2	1000/1/0	96	19	68	0.47
1-1/2	3000	3450**	1000/1/2	1000/1/0	96	19	71	0.47
1-1/2	3000	3400**	1000/1/2	1000/1/0	96	19	70	0.47
1	350	360	200/1/2	400/1/0	68	30	56	--*
1	350	344	200/1/2	400/1/0	68	30	53	--*
1	350	362	200/1/2	400/1/0	68	32	56	--*
1	350	366	200/1/2	400/1/0	68	32	57	--*
1	350	455	200/1/2	400/1/0	68	32	70	--*
1	350	415	200/1/2	400/1/0	68	32	64	--*
1	350	430	200/1/2	400/1/0	68	32	67	--*
1	350	443	200/1/2	400/1/0	68	32	69	--*
1	350	426	200/1/2	200/1/0	68	50	65	0.09
1	350	436	200/1/2	200/1/0	68	50	66	0.09
1	350	458	200/1/2	200/1/0	62	44	76	0.08

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVALR 29 NARROW FABRICS (cont)

Width	Tensile Strength (lb)		Denier/Ply/Twist		Total	Pick	Strength[1] Translational Efficiency	Weight (oz/
(inch)	Target	Actual	Warp	Filling	Ends	Wheel[2]	(%)	lin yd)
1	350	421	200/1/2	200/1/0	62	44	70	0.08
1	350	470	200/1/2	200/1/0	62	44	78	0.08
1	350	395	200/1/2	200/1/0	62	42	66	0.08
1	350	373	200/1/2	200/1/0	62	42	62	0.08
1	350	329	200/1/2	200/1/0	62	42	55	0.08
1	350	449	200/1/2	200/1/0	56	42	83	0.08
1	350	467	200/1/2	200/1/0	56	42	86	0.08
1	350	388	200/1/2	200/1/0	50	42	80	0.07
1	350	408**	200/1/2	200/1/0	50	42	84	0.07
1	350	397**	200/1/2	200/1/0	50	42	82	0.07
1	350	409**	200/1/2	200/1/0	50	42	84	0.07
1	350	405**	200/1/2	200/1/0	50	42	84	0.07
1	350	415**	200/1/2	200/1/0	50	42	86	0.07
1	350	397**	200/1/2	200/1/0	50	42	82	0.07
1	350	418**	200/1/2	200/1/0	50	42	86	0.07
1	750	940	200/1/2	200/1/0	114	36	85	--*
1	750	905	200/1/2	200/1/0	114	36	82	--*
1	750	970	200/1/2	200/1/0	114	36	80	--*
1	750	875**	200/1/2	200/1/0	108	35	83	0.11
1	750	820**	200/1/2	200/1/0	108	35	78	0.11
1	750	850**	200/1/2	200/1/0	108	35	81	0.11
1	1500	1450	400/1/5	200/1/0	104	33	63	--*
1	1500	1410	400/1/5	200/1/0	104	33	62	--*
1	1500	1465	400/1/5	1000/1/0	104	24	64	--*
1	1500	1520	400/1/5	1000/1/0	104	24	66	--*
1	1500	1515	400/1/5	1000/1/0	104	22	66	--*
1	1500	1600	400/1/5	1000/1/0	104	22	70	--*
1	1500	1420	400/1/5	1000/1/0	104	22	62	--*
1	1500	1480	400/1/5	1000/1/0	104	22	65	--
1	1500	1540	400/1/5	1000/1/0	104	22	67	--*
1	1500	1570	400/1/5	1500/1/0	104	16	69	--*
1	1500	1615	400/1/5	1500/1/0	104	16	71	--*
1	1500	1635	400/1/5	1500/1/0	104	18	71	--*
1	1500	1550	400/1/5	1500/1/0	104	18	68	--*
1	1500	1500	400/1/5	1500/1/0	104	22	66	--*
1	1500	1385	400/1/5	400/1/0	104	30	61	--*
1	1500	1340	400/1/5	400/1/0	104	30	59	--*
1	1500	1300	400/1/5	400/1/0	104	30	57	--*
1	1500	1520	400/1/5	400/1/0	104	27	66	--*
1	1500	1520	400/1/5	400/1/0	104	27	66	--*
1	1500	1610**	400/1/2	400/1/0	108	26	80	0.21
1	1500	1590**	400/1/2	400/1/0	108	26	70	0.21
1	1500	1690**	400/1/2	400/1/0	108	26	71	0.21
1	1500	1660**	400/1/2	400/1/0	108	26	70	0.21

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

COMPILATION OF TENSILE TESTS PERFORMED DURING DESIGN OF EXPERIMENTAL KEVLAR 29 NARROW FABRICS (cont)

Width (inch)	Tensile Strength (lb) Target	Tensile Strength (lb) Actual	Denier/Ply/Twist Warp	Denier/Ply/Twist Filling	Total Ends	Pick Wheel[2]	Strength Translational Efficiency[1] (%)	Weight (oz/ lin yd)
1	3000	3260	1000/1/4	1000/1/0	96	16	67	--*
1	3000	3310	1000/1/4	1000/1/0	96	18	68	--*
1	3000	3250	1000/1/4	400/1/0	96	18	67	--*
1	3000	3075	1000/1/4	400/1/0	96	18	63	--*
1	3000	3080	1000/1/4	400/1/0	96	17	63	--*
1	3000	3330	1000/1/4	400/1/0	96	17	68	--*
1	3000	3075	1000/1/4	400/1/0	96	18	63	--*
1	3000	3180	1000/1/4	400/1/0	96	18	65	--*
1	3000	3475	1000/1/4	400/1/0	96	16	71	--*
1	3000	3025	1000/2/2	1500/1/0	48	16	67	--*
1	3000	3000	1000/2/2	1500/1/0	48	16	67	--*
1	3000	3360	1000/2/2	400/2/0	48	16	74	--*
1	3000	3270	1000/2/2	400/2/0	48	16	72	--*
1	3000	3250	1000/2/2	400/2/0	48	16	72	--*
1	3000	3175	1000/2/2	400/2/0	48	16	70	--*
1	3000	3280	1000/2/2	400/2/0	48	16	73	--*
1	3000	3100	1000/2/2	400/2/3	48	16	69	--*
1	3000	3110	1000/2/2	400/2/3	48	16	69	--*
1	3000	3080	1000/2/2	400/2/3	48	16	69	--*
1	3000	3250	1000/2/2	1000/1/0	48	16	72	0.42
1	3000	3240	1000/2/2	1000/1/0	48	16	72	0.42
1	3000	3175	1000/2/2	1000/1/0	48	16	70	0.42
1	3000	3150	1000/2/2	1000/1/0	48	16	70	0.42
1	3000	3175	1000/2/2	1000/1/0	48	16	70	0.42
1	3000	3160	1000/2/2	1000/1/0	48	15	70	0.42
1	3000	3430**	1000/2/2	1000/1/0	48	15	76	0.42
1	3000	3450**	1000/2/2	1000/1/0	48	15	77	0.42
1	3000	3220**	1000/2/2	1000/1/0	48	15	71	0.42
1/2	800	855	200/1/2	200/1/0	122	37	72	0.11
1/2	800	800	200/1/2	200/1/0	122	37	68	0.11
1/2	800	866	200/1/2	200/1/0	122	37	73	0.11
1/2	800	820	200/1/2	200/1/0	122	37	72	0.11
1/2	800	850	200/1/2	200/1/0	122	37	74	0.11
1/2	800	870**	200/1/2	200/1/0	122	37	73	0.11
1/2	800	860**	200/1/2	200/1/0	122	37	76	0.11
1/2	800	900**	200/1/2	200/1/0	122	37	76	0.11

*Not determined.

**Tensile breaks on production item.

1. Individual warp yarn strengths: 9.7 lb for 200 denier; 22.0 lb for 400 denier; 50.7 lb for 1000 denier; 72.7 lb for 1500 denier; 93.9 lb for 1000/2 ply.
2. Loom setting - actual picks/inch may differ slightly.

☆U.S.Government Printing Office: 1979 — 657-002/452